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出願年月日
Date of Application: ２００１年　２月２８日

出願番号
Application Number: 特願２００１－０５４２５４

出願人
Applicant(s): 日立マクセル株式会社

２００１年　９月１４日

特許庁長官
Commissioner,
Japan Patent Office
及川耕造

出証番号　出証特２００１－３０８５２５０

【書類名】　特許願
【整理番号】　HM0106
【提出日】　平成13年 2月28日
【あて先】　特許庁　長官殿
【国際特許分類】　G11B 11/10
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【手数料の表示】
【予納台帳番号】　057521
【納付金額】　21,000円
【提出物件の目録】
【物件名】　明細書　1
【物件名】　図面　1
【物件名】　要約書　1
【包括委任状番号】　9500734
【プルーフの要否】　要

【書類名】　明細書

【発明の名称】　磁気記録媒体及び磁気記録装置

【特許請求の範囲】

【請求項１】　磁気記録媒体であって、

強磁性材料から形成された記録層と；

強磁性材料から形成され、記録層の磁化を安定化させる磁化安定化層と；

上記記録層と上記磁化安定化層との間に存在する非磁性層と；

上記非磁性層と記録層の間並びに非磁性層と磁化安定化層の間の少なくとも一方に存在し、上記記録層と上記磁化安定化層との間の交換結合を増大するエンハンス層とを含む磁気記録媒体。

【請求項２】　上記エンハンス層が、Ｃｏ、Ｎｉ、Ｆｅ及びＣｏＮｉＦｅ合金からなる群から選ばれた一種から形成されていることを特徴とする請求項１に記載の磁気記録媒体。

【請求項３】　上記エンハンス層が、Ｃｏ、ＮｉまたはＦｅと遷移金属との合金から形成されていることを特徴とする請求項１に記載の磁気記録媒体。

【請求項４】　上記記録層または上記磁化安定化層がＣｏ、ＮｉまたはＦｅを含む材料から形成されており、上記エンハンス層は記録層または上記磁化安定化層よりも高濃度のＣｏ、ＮｉまたはＦｅを含む材料から形成されていることを特徴とする請求項１に記載の磁気記録媒体。

【請求項５】　上記エンハンス層が、上記非磁性層と磁化安定化層の間に存在する第１エンハンス層と、上記非磁性層と記録層の間に存在する第２エンハンス層とを含むことを特徴とする請求項１～４のいずれか一項に記載の磁気記録媒体。

【請求項６】　上記エンハンス層が、０．２～２ｎｍの膜厚を有することを特徴とする請求項１～５のいずれか一項に記載の磁気記録媒体。

【請求項７】　上記非磁性層が、Ｒｕから形成されていることを特徴とする請求項１～６のいずれか一項に記載の磁気記録媒体。

【請求項８】　上記磁化安定化層が第１及び第２磁化安定化層を含み、上記非磁性層が第１及び第２非磁性層を含み、第１非磁性層は第１磁化安定化層と第

２磁化安定化層の間に形成され、第２非磁性層は第２磁化安定化層と記録層との間に形成されており、上記エンハンス層が第２非磁性層と記録層の間並びに第２非磁性層と第２磁化安定化層の間の少なくとも一方に存在し、第１磁化安定化層と第１非磁性層の間並びに第１非磁性層と第２磁化安定化層の間の少なくとも一方に第１磁化安定化層と第２磁化安定化層との間の交換結合を増大する補助エンハンス層を備える請求項１～７のいずれか一項に記載の磁気記録媒体。

【請求項９】　上記補助エンハンス層が、第１非磁性層及び第１磁化安定化層の間に形成された第１補助エンハンス層と；第１非磁性層及び第２磁化安定化層の間に形成された第２補助エンハンス層と；を含む請求項８に記載の磁気記録媒体。

【請求項１０】　さらに、下地層が形成された基板を備え、該下地層上に、上記磁化安定化層を備えることを特徴とする請求項１～９のいずれか一項に記載の磁気記録媒体。

【請求項１１】　磁気記録媒体であって、

強磁性材料から形成された記録層と；

強磁性材料から形成され、記録層の磁化を安定化させる磁化安定化層と；

上記記録層と上記磁化安定化層との間に存在する非磁性層と；を備え、

上記磁気記録媒体の外部磁界に対する磁化曲線がヒステリシスループを示し、磁化を飽和させた後に外部磁界を低下させたときに、外部磁界に対する磁化の変化率が極大を示す点が正の外部磁界の領域に存在し、且つ磁化曲線から求めた交換結合磁界が１ｋＯｅ以上であることを特徴とする磁気記録媒体。

【請求項１２】　さらに、上記非磁性層と記録層の間並びに非磁性層と磁化安定化層の間の少なくとも一方に存在し、上記記録層と上記磁化安定化層との間の交換結合を増大するエンハンス層を含むことを特徴とする請求項１１に記載の磁気記録媒体。

【請求項１３】　上記記録層及び磁化安定化層がＣｏ、ＮｉまたはＦｅを含み、エンハンス層がＣｏ、ＮｉまたはＦｅから形成されていることを特徴とする請求項１１または１２に記載の磁気記録媒体。

【請求項１４】　上記磁化安定化層は、上記記録層を形成する強磁性材料よ

りも磁性原子濃度の高い強磁性材料から形成されていることを特徴とする請求項１１に記載の磁気記録媒体。

【請求項１５】　上記磁化安定化層が、Ｃｏ、Ｎｉ、Ｆｅ及びＣｏＮｉＦｅ合金からなる群から選ばれた一種から形成されていることを特徴とする請求項１４に記載の磁気記録媒体。

【請求項１６】　上記磁化安定化層が、Ｃｏ、ＮｉまたはＦｅと遷移金属との合金から形成されていることを特徴とする請求項１４に記載の磁気記録媒体。

【請求項１７】　上記記録層がＣｏ、ＮｉまたはＦｅを含む材料から形成されていることを特徴とすることを特徴とする請求項１５または１６に記載の磁気記録媒体。

【請求項１８】　磁気記録媒体であって、

強磁性材料から形成された記録層と；

上記記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料から形成された補助磁性層と；

上記記録層と補助磁性層との間に形成された非磁性層と；を含む磁気記録媒体。

【請求項１９】　上記補助磁性層が、Ｃｏ、Ｎｉ、Ｆｅ及びＣｏＮｉＦｅ合金からなる群から選ばれた一種から形成されていることを特徴とする請求項１８に記載の磁気記録媒体。

【請求項２０】　上記補助磁性層が、Ｃｏ、ＮｉまたはＦｅと遷移金属との合金から形成されていることを特徴とする請求項１８に記載の磁気記録媒体。

【請求項２１】　上記記録層がＣｏ、ＮｉまたはＦｅを含む材料から形成されていることを特徴とする請求項１９または２０に記載の磁気記録媒体。

【請求項２２】　更に、上記記録層と非磁性層との間に、上記補助磁性層と記録層との交換結合を増大するエンハンス層を備える請求項１８～２１のいずれか一項に記載の磁気記録媒体。

【請求項２３】　上記非磁性層が、Ｒｕから形成されていることを特徴とする請求項１８～２２のいずれか一項に記載の磁気記録媒体。

【請求項２４】　上記補助磁性層が、１～５ｎｍの膜厚を有することを特徴

とする請求項１８～２３のいずれか一項に記載の磁気記録媒体。

【請求項２５】　更に、基板と、第２の非磁性層と、強磁性材料から形成され且つ記録層の磁化を安定化させる磁化安定化層とを含み、上記基板と補助磁性層との間で、補助磁性層に近い側に第２の非磁性層が位置付けられていることを特徴とする請求項１８～２４のいずれか一項に記載の磁気記録媒体。

【請求項２６】　更に、基板と第２の非磁性層と第２の補助磁性層とを含み、上記基板と補助磁性層との間で、補助磁性層に近い側に第２の非磁性層が位置付けられていることを特徴とする請求項１８～２４のいずれか一項に記載の磁気記録媒体。

【請求項２７】　更に、上記基板上に形成された下地層を備えることを特徴とする請求項２５または２６のいずれか一項に記載の磁気記録媒体。

【請求項２８】　上記記録層が面内方向の磁化を有する請求項1、１１及び１８のいずれか一項に記載の磁気記録媒体。

【請求項２９】　請求項1、１１及び１８のいずれか一項に記載の磁気記録媒体と；

上記磁気記録媒体に情報を記録又は再生するための磁気ヘッドと；

上記磁気記録媒体を上記磁気ヘッドに対して駆動するための駆動装置と；を含む磁気記録装置。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】

本発明は、磁気記録媒体及び磁気記録装置に関し、特に、熱安定性に優れ、高密度記録に好適な面内磁気記録媒体及びその面内磁気記録媒体を装着した磁気記録装置に関する。

【０００２】

【従来の技術】

近年の高度情報化社会の進展にはめざましいものがあり、文字情報のみならず音声及び画像情報を高速に処理することができるマルチメディアが普及してきている。マルチメディアの一つとしてコンピュータ等に装着される磁気記録装置が

知られている。現在、このような磁気記録装置の記録密度を向上させつつ小型化する方向に開発が進められている。

【０００３】

典型的な磁気記録装置は複数の磁気ディスクをスピンドル上に回転可能に装着している。各磁気ディスクは基板とその上に形成された磁性膜から構成されており、情報の記録は特定の磁化方向を有する磁区を磁性膜中に形成することにより行なわれる。

【０００４】

このような磁気記録装置の高密度記録化を実現するためには、磁性膜を構成する粒子径を微小化するとともに各粒子間の相互作用を低下させることが要望されている。しかしながら、粒子径の微小化と粒子間相互作用の低下は、粒子の熱安定性を低下させるという問題がある。

【０００５】

磁気ディスク、特に面内方向の磁化を有する磁気ディスクの熱安定性を向上させる技術として、記録層の下地層として、軟磁性のいわゆるキーパー層を設ける方法や記録層の磁化と逆向きの磁化を有する層を設ける方法が知られている。後者の方法の一つとして、図６に示したように、磁気ディスクのＣｏＣｒＰｔＢ記録層とＣｏＣｒＰｔＢ磁化安定化層との間に、磁気結合層としてのＲｕ薄膜を形成することにより熱安定性を向上させる技術がE.N. Abarra et al.の文献に発表されている（E.N. Abarra et al. TECHNICAL REPORT OF IEICE. MR2000-34(2000-10)）。図６に示した磁気ディスク構造において、記録層と磁化安定化層との間に磁気結合層として０．５～１ｎｍ程度の厚みのＲｕ層を介在させると、記録層と磁化安定化層との間に反強磁性的な交換結合が働く。従って、それらの層は反平行の磁化を有するために、記録層の磁化が磁化安定化層により安定化される。このＲｕ層による反強磁性的な交換結合は、記録層の磁化を一層熱的に安定化させ、磁気ディスクの記録再生特性を改善することができることがこの文献に示されている。

【０００６】

【発明が解決しようとする課題】

しかしながら、磁気記録装置のさらなる高密度記録化を実現するには、上記文献に開示された磁気ディスクよりも一層熱安定性に優れた磁気ディスクを備える磁気記録装置が要求されている。

【０００７】

本発明の第１目的は、熱安定性に優れた磁気記録媒体、特に面内磁気記録媒体及びそれを備えた磁気記録装置を提供することにある。

【０００８】

本発明の第２の目的は、記録した情報の安定性（記録安定性）に優れた磁気記録装置を提供することにある。

【０００９】

本発明の第３の目的は、高密度磁気記録に適した磁気記録媒体及びそれを装着した磁気記録装置を提供することにある。

【００１０】

【課題を解決するための手段】

本発明の第１の態様に従えば、磁気記録媒体であって、

強磁性材料から形成された記録層と；

強磁性材料から形成され、記録層の磁化を安定化させる磁化安定化層と；

上記記録層と上記磁化安定化層との間に存在する非磁性層と；

上記非磁性層と記録層の間並びに非磁性層と磁化安定化層の間の少なくとも一方に存在し、上記記録層と上記磁化安定化層との間の交換結合を増大するエンハンス層とを含む磁気記録媒体が提供される。

【００１１】

本発明者は、図６に示した従来型構造を有する磁気ディスクをさらに改良させるべく研究を重ねたところ、Ｒｕ層（非磁性層）と記録層との界面及び／またはＲｕ層（非磁性層）と磁化安定化層との界面に、数原子層のＣｏ層を介在させることにより、上記記録層と上記磁化安定化層との間の交換結合を著しく向上させることができることを見出した。上記界面に介在させる層はＣｏのみならず、記録層と磁化安定化層の間の交換結合を向上させることができる後述する種々の物質から構成することができ、本明細書においてはこの層を記録層と磁化安定化層

の間の交換結合を増大（エンハンス）させる層、すなわち、「エンハンス層」と称する。

【００１２】

本発明者の知見によると、このエンハンス層が、記録層と磁化安定化層との間の交換結合を向上させることができる理由は以下の通りである。図６に示した従来型の磁気ディスクでは、ＣｏＣｒＰｔＢ記録層とＣｏＣｒＰｔＢ磁化安定化層がＲｕ層を介して積層されている。ここで、記録層と磁化安定化層はＲｕ原子層を介して交換結合している。この交換結合は、記録層と磁化安定化層中のＣｏ原子同士がＲｕ原子を介して電子軌道が結合していることに基づくと考えられる。このような結合は、例えば、GMRヘッドにおける人工格子中の結合にも見られる。

【００１３】

しかしながら、記録層とＲｕ層との界面を観察すると、記録層は、ＣｏＣｒＰｔＢから構成されているために、記録層の結晶粒子はＣｏリッチでありその粒界はＣｒリッチな組成を示しており、この結果、記録層のＲｕ層側の表面にはＣｏ原子よりも多くのＣｒの原子が露出していると考えられる。磁化安定化層もまた記録層と同様にＣｏＣｒ合金（ＣｏＣｒＰｔＢ）から構成されているために、磁化安定層のＲｕ層側の表面にはＣｏを覆うＣｒ原子が多量に露出していると考えられる。これらのＣｒ原子層は、前述のＲｕ原子を介する記録層と磁化安定化層中のＣｏ原子同士の電子結合を阻害し、記録層と磁化安定化層の交換結合を弱めていると考えられる。本発明では、Ｃｒ原子が表面に露出している記録層または磁化安定化層をエンハンス層で覆うことにより、記録層と磁化安定化層との交換結合をエンハンス層を構成するＣｏなどの原子間における交換結合により改善させていると考えられる。

【００１４】

エンハンス層は、Ｃｏ、ＮｉもしくはＦｅまたはＣｏＮｉＦｅ合金から形成し得る。または、エンハンス層は、Ｃｏ、ＮｉまたはＦｅと、遷移金属、特に、Ｐｔ、Ａｕ、Ａｇ、Ｃｕ、Ｐｄなどの貴金属との合金から形成され得る。それらの原子または合金は、非磁性層を介して電子的に結合して交換結合磁界を増大する

働きがある。あるいは、記録層または磁化安定化層がＣｏ、ＮｉまたはＦｅを含む材料から形成されている場合には、記録層または磁化安定化層より高濃度のＣｏ、ＮｉまたはＦｅを含む材料からエンハンス層を形成することもまた有効である。

【００１５】

上記エンハンス層は、上記非磁性層と記録層の間並びに非磁性層と磁化安定化層の間の少なくとも一方に存在すればよいが、非磁性層と磁化安定化層の間に存在する第１エンハンス層と、非磁性層と記録層の間に存在する第２エンハンス層とを含むことが記録層と磁化安定化層の間の交換結合を一層高めるために望ましい。

【００１６】

上記磁化安定化層が第１及び第２磁化安定化層を含み、上記非磁性層が第１及び第２非磁性層を含み、第１非磁性層は第１磁化安定化層と第２磁化安定化層の間に形成され、第２非磁性層は第２磁化安定化層と記録層との間に形成されていても良い。この場合、上記エンハンス層が第２非磁性層と記録層の間並びに第２非磁性層と第２磁化安定化層の間の少なくとも一方に存在し、第１磁化安定化層と第１非磁性層の間並びに第１非磁性層と第２磁化安定化層の間の少なくとも一方に第１磁化安定化層と第２磁化安定化層との間の交換結合を増大する補助エンハンス層を備え得る。さらに、上記補助エンハンス層が、第１非磁性層及び第１磁化安定化層の間に形成された第１補助エンハンス層と；第１非磁性層及び第２磁化安定化層の間に形成された第２補助エンハンス層と；を含み得る。補助エンハンス層は、上記エンハンス層と同じ材料から構成され得る。

【００１７】

上記エンハンス層（及び補助エンハンス層）は、交換結合のエンハンス効果を有意義にするために、０．２～３ｎｍ、好ましくは、０．２～２ｎｍの膜厚を有することが望ましい。

【００１８】

非磁性層は、Ｒｕから形成され得るが、これに限らず、Ｒｈ、Ｉｒ、Ｈｆ、Ｃｕ、Ｃｒ、Ａｇ、Ａｕ、Ｒｅ、Ｍｏ、Ｎｂ、Ｗ、Ｔａ、Ｖなどの遷移金属、Ｃｏ

ＣｒＲｕのようなＣｏＣｒ系の非磁性合金を用い得る。交換結合を一層高めるためにはＲｕが望ましい。なお、本発明においてこの非磁性層は記録層と磁化安定化層とを磁気的に結合する働きを有するので磁気結合層とも呼ぶ。

【００１９】

本発明の磁気記録媒体において記録層は結晶質であって、該結晶質相がコバルト（Ｃｏ）を主体とした合金にしてよい。このＣｏ合金においては、ＣｏにＣｒ、Ｐｔ、Ｔａ、Ｎｂ、Ｔｉ、Ｓｉ、Ｂ、Ｐ、Ｐｄ、Ｖ、Ｔｂ、Ｇｄ、Ｓｍ、Ｎｄ、Ｄｙ、Ｈｏ、若しくはＥｕ、又はそれらの組み合わせを含み得る。

【００２０】

ここで、記録層にクロム（Ｃｒ）を含むと、Ｃｏを主体とした結晶粒子（磁性粒子）の粒界近傍又は粒界部にＣｒの偏析部分を形成することができる。記録層中にさらにＴａ、Ｎｂ、Ｔｉ、Ｂ若しくはＰ、又はそれらの元素の組み合わせを含むと、Ｃｒの偏析が促進される。この偏析によって、磁性粒子間の磁気的相互作用が低減でき、磁化反転単位を構成する磁性粒子数を減らすことができる。従って、ＣｏＣｒ合金に上記添加物を含む記録層に本発明のエンハンス層を組み合わせて用いることで、微小な磁化反転単位でありながらも熱揺らぎに強い磁気記録媒体をもたらすことができる。

【００２１】

本発明の磁気記録媒体は、さらに、基板、基板上に形成された下地層を備え得る。この場合、下地層上に、磁化安定化層を備え得る。基板はガラス、ポリカーボネートなどのプラスチックから形成し得る。下地層は、Ｃｒ若しくはＮｉ、又は、Ｃｒ合金若しくはＮｉ合金から形成され得る。Ｃｒ合金又はＮｉ合金は、母元素以外にＣｒ、Ｔｉ、Ｔａ、Ｖ、Ｒｕ、Ｗ、Ｍｏ、Ｎｂ、Ｎｉ、ＺｒまたはＡｌを含み得る。下地層は、磁性層の結晶配向性や格子定数を制御する目的で使用される。下地層は、単層または複数層で用いることも可能である。

【００２２】

本発明の第２の態様に従えば、磁気記録媒体であって、

強磁性材料から形成された記録層と；

強磁性材料から形成され、記録層の磁化を安定化させる磁化安定化層と；

上記記録層と上記磁化安定化層との間に存在する非磁性層と；を備え、

上記磁気記録媒体の外部磁界に対する磁化曲線がヒステリシスループを示し、磁化を飽和させた後に外部磁界を低下させたときに、外部磁界に対する磁化の変化率が極大を示す点が正の外部磁界の領域に存在し、且つ磁化曲線から求めた交換結合磁界が１ｋＯｅ以上であることを特徴とする磁気記録媒体が提供される。

【００２３】

本発明の磁化安定化層を有する磁気記録媒体は、例えば、図４に示すような磁化曲線で表されるヒステリシスループで表される磁気特性を有する。このヒステリシスループでは、磁気記録媒体の磁化を飽和させた後に外部磁界を低下させたときに、外部磁界に対する磁化の変化率が極大を示す点が正の外部磁界の領域に存在する。このように磁化の変化率が急激に変化するのは、磁気記録媒体の磁化が飽和しているときには、記録層と磁化安定化層の磁化がともに平行であり、外部磁界が低下して磁化の変化率が極大となる領域で磁化安定化層の磁化が反転して記録層の磁化を安定化させるためであると考えられる。この領域では、図４に示すようにマイナーヒステリシスループが観測され得る。このマイナーヒステリシスループを図５に示す。マイナーヒステリシスループの中心点から求めた交換結合磁界H_{ex}は、１ｋＯｅ以上、好ましくは１．５ｋＯｅ以上であり、図６に示した従来型の磁気記録媒体に比べて著しく大きく、それゆえ、本発明の磁気記録媒体は熱安定性に優れることが分かる。

【００２４】

このような大きな交換結合磁界H_{ex}を生じさせるには、例えば、非磁性層と記録層の間並びに非磁性層と磁化安定化層の間の少なくとも一方に、前述のエンハンス層を存在させればよい。

【００２５】

あるいは、磁化安定化層を、記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料を用いて形成することによっても、大きな交換結合磁界H_{ex}を生じさせることができる。かかる強磁性材料には、前述のエンハンス層に用い得る材料と同じ材料が好適であり、例えば、記録層がＣｏ、ＮｉまたはＦｅを含む強磁性材料から形成されている場合には、記録層より高濃度のＣｏ、Ｎｉまた

はＦｅを含む強磁性材料から形成することができる。また、補助磁性層は、Ｃｏ、ＮｉもしくはＦｅなどの単体金属またはＣｏＮｉＦｅ合金を用いることもできる。または、Ｃｏ、ＮｉまたはＦｅと、遷移金属、特に、Ｐｔ、Ａｕ、Ａｇ、Ｃｕ、Ｐｄなどの貴金属との合金を用いて形成することもできる。このように、第２の態様の磁気記録媒体において、磁化安定化層を、記録層よりも磁性原子濃度の高い強磁性材料を用いて形成した場合、磁化安定化層は、後述する第３の態様の磁気記録媒体の補助磁性層と同様に記録層との間で強い交換結合力を示すので、記録層の磁化を安定化させることができる。すなわち、記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料で形成された磁化安定化層は、第３の態様の磁気記録媒体の補助磁性層と同様の機能を有する。本発明の第２の態様の磁気記録媒体における磁化安定化層は、第３の態様の磁気記録媒体の補助磁性層を含む概念である。

【００２６】

本発明の第３の態様に従えば、磁気記録媒体であって、

強磁性材料から形成された記録層と；

上記記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料から形成された補助磁性層と；

上記記録層と補助磁性層との間に形成された非磁性層と；を含む磁気記録媒体が提供される。

【００２７】

本発明の第３の態様の磁気記録媒体は、非磁性層を介して記録層と交換結合する補助磁性層を、記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料を用いて形成する。かかる磁性材料としては、上述のエンハンス層と同様の強磁性材料を用いることができる。例えば、記録層がＣｏ、ＮｉまたはＦｅを含む強磁性材料から形成されている場合には、記録層よりも高濃度のＣｏ、ＮｉまたはＦｅなどの磁性原子を含む強磁性材料から形成することができる。また、補助磁性層は、Ｃｏ、ＮｉもしくはＦｅなどの単体金属またはＣｏＮｉＦｅ合金から形成することもできる。または補助磁性層は、Ｃｏ、ＮｉまたはＦｅと、遷移金属、特に、Ｐｔ、Ａｕ、Ａｇ、Ｃｕ、Ｐｄなどの貴金属との合金からも形成さ

れ得る。このように、上述のエンハンス層と同様の強磁性材料から形成された補助磁性層により、補助磁性層と記録層との間に生じる交換結合力は、従来技術の欄で記載したような磁気記録媒体の磁化安定化層と記録層との間で生じる交換結合力よりも大きくなる。それゆえ、記録層の熱安定性は従来よりも一層高まり、更なる高密度記録を実現することができる。

【００２８】

上述したように、本発明の第１の態様の磁気記録媒体は、磁化安定化層で安定化された記録層の磁化を、エンハンス層を設けて磁化安定化層と記録層との間の交換結合力を増大させることによって、より一層安定化させていたが、第３の態様の磁気記録媒体は、補助磁性層と記録層との間に強い交換結合力が発生しているので、第１の態様の磁気記録媒体と同様に、記録層の磁化を安定化させることができる。したがって、本発明の第３の態様の磁気記録媒体は、第１の態様の磁気記録媒体よりも簡単な構成で記録層の熱安定性を向上させることができる。

【００２９】

本発明の第３の態様に従う磁気記録媒体において、補助磁性層は、記録層との間で働く交換結合力を有意義にするために１ｎｍ～５ｎｍの膜厚を有することが好ましい。

【００３０】

本発明の第３の態様の磁気記録媒体は、非磁性層と記録層との間に、記録層と補助磁性層との間で生じる交換結合力を更に増大させるためのエンハンス層を設けることができる。エンハンス層は、第１の態様の磁気記録媒体のエンハンス層と同様の材料を用いて形成し得る。かかるエンハンス層は、記録層と補助磁性層との間で働く交換結合のエンハンス効果を有意義にするために０．２～２．０ｎｍの膜厚を有することが望ましい。

【００３１】

本発明の第３の磁気記録媒体は、更に、基板と、第２の非磁性層と、記録層の磁化を熱的に安定化させる磁化安定化層とを備え得、補助磁性層と基板との間に第２の非磁性層と磁化安定化層が存在し、且つ第２の非磁性層が補助磁性層に近い側に位置付けられて構成される。第２の非磁性層は、上述の非磁性層と同じ材

料から構成され得、磁化安定化層は、例えば、記録層と同じ材料から構成され得る。かかる磁気記録媒体は、磁化安定化層により、記録層の磁化をより一層安定化させることができる。

【００３２】

また、本発明の第３の態様の磁気記録媒体は、基板と第２の非磁性層と第２の補助磁性層とを備えることができ、上記基板と補助磁性層との間に第２の非磁性層と第２の補助磁性層が存在し且つ補助磁性層に近い側に第２の非磁性層が位置するように構成され得る。第２の補助磁性層は、前述のエンハンス層と同じ材料を用いて形成し得る。かかる構造の磁気記録媒体は、第２の補助磁性層を形成したことにより、交換結合磁界がより一層増大しているので熱安定性に極めて優れる。

【００３３】

本発明の第４の態様に従えば、本発明の第１、第２または第３の態様に従う磁気記録媒体と；

上記磁気記録媒体に情報を記録又は再生するための磁気ヘッドと；

上記磁気記録媒体を上記磁気ヘッドに対して駆動するための駆動装置と；を含む磁気記録装置が提供される。

【００３４】

本発明に従う磁気記録装置は、熱安定性に優れた磁気記録媒体を装着しているために、長時間に渡る記録安定性に優れる。

【００３５】

【発明の実施の形態】

以下に、本発明の磁気記録媒体及び磁気記録装置を実施例及び比較例を用いて具体的に説明する。ただし、本発明はこれらの実施例に限定されない。

【００３６】

【実施例１】

本発明に従う磁気記録媒体の典型例を図１の断面図に示す。磁気記録媒体１０は、ガラス基板２０上に、第１下地層２、第２下地層４、磁化安定化層６、第１エンハンス層８、磁気結合層（非磁性層）１２、第２エンハンス層８、記録層１

６及び保護層１８を備える。各層は以下のようにＤＣマグネトロンスパッタ装置を用いてスパッタリングにより形成した。

【００３７】

直径２．５ｉｎｃｈ（６．２５ｃｍ）のガラス基板２０上に、第１金属下地層２として、ＮｉＡｌ膜をＤＣマグネトロンスパッタ装置を用いてスパッタリングにより形成した。ターゲットには原子比でＮｉ：Ａｌ＝５０：５０のＮｉＡｌ合金を用いた。ＮｉＡｌ膜の膜厚は５０ｎｍであった。スパッタ時のＡｒガス圧は０．３Ｐａ、投入電力は０．５ｋＷであった。基板は、スパッタ開始前に、スパッタ室を１×１０$^{-5}$Ｐａ以下に減圧した後に３４０℃に加熱した。この条件下での成膜速度は約３ｎｍ／秒であった。

【００３８】

第２金属下地層４として、ＣｒＭｏ膜を第１金属下地層２上に膜厚２０ｎｍで形成した。ターゲットにはＭｏ：２７原子％のＣｒＭｏ合金を用いた。成膜条件は、第１金属下地層２の場合と同様にした。

【００３９】

磁化安定化層６として、ＣｏＣｒＰｔＢ膜を第１金属下地層４上に膜厚６ｎｍで形成した。ターゲットには$Co_{64}Cr_{20}Pt_{12}B_{4}$合金を用いた。成膜条件は、第１金属下地層２の場合と同様にした。

【００４０】

次いで、第１エンハンス層８として、Ｃｏ膜を磁化安定化層６上に膜厚１ｎｍで形成した。ターゲットにはＣｏを用いた。スパッタ時の成膜条件として、投入電力は１００Ｗとし、基板とターゲット間の間隔を長くした以外は、第１金属下地層２の場合と同様にした。

【００４１】

次いで、磁気結合層１２として、Ｒｕ膜を第１エンハンス層８上に膜厚０．８ｎｍで形成した。ターゲットにはＲｕを用いた。スパッタ時の成膜条件は、第１エンハンス層８の場合と同様にした。

【００４２】

第２エンハンス層１４としてのＣｏ膜を、第１エンハンス層８と同様に形成し

た。第１エンハンス層８及び第２エンハンス層１４は、記録層１６と磁化安定化層６との間の交換結合を増大させる働きを有する。

【００４３】

記録層１６として、面内方向の磁化を有するＣｏＣｒＰｔＢ膜を第２エンハンス層１４上に膜厚１８ｎｍで形成した。ターゲットには$Co_{64}Cr_{20}Pt_{12}B_4$合金を用いた。成膜条件は、磁化安定化層６の場合と同様にした。

【００４４】

最後に、ＣｏＣｒＰｔＢ記録層１６上に、保護膜としてのカーボン層を膜厚５ｎｍで形成した。成膜条件は、第１金属下地層２の場合と同様であった。こうして図１に示した構造の磁気ディスク１０を製造した。

【００４５】

【比較例１】

比較例として、第１及び第２エンハンス層を形成しなかった以外は、実施例１と同様にして磁気ディスクを製造した。図７に、こうして得られた比較例の磁気ディスク５０の構造を示す。

【００４６】

［磁化曲線の評価］

実施例１で製造した磁気ディスクの磁化特性を以下のようにして測定した。ＶＳＭ（Vibration Sample Magnetometer）により磁界を印加して外部磁界に対する磁化曲線を観測した。得られた結果を図４に示す。図４のヒステリシスループから分かるように、正方向の外部磁界を印加して磁化を飽和させた後、外部磁界を低下させてゆくと、外部磁界がゼロになる前に磁化が急激に低下する領域が存在する。この領域では、外部磁界に対する磁化の変化率（δＭ／δＨ）が極大となる点が現れている。そしてこの領域では磁化曲線がヒステリシスを示すマイナーループを描いている。このマイナーループが生じるのは、変化率の極大点に至る前は記録層１６と磁化安定化層６の磁化の向きが平行であるが、極大点を境に磁化安定化層６の磁化の向きが反転するためであると考えられる。

【００４７】

図５（ａ）にマイナーループの拡大図を示す。このマイナーループは、正方向

の外部磁界を印加して記録層及び磁化安定化層の磁化を飽和させた後、磁界を低下させてゆき、磁化の変化率が安定化した後に、再度外部磁界を増加させることにより求めた磁化曲線である。ここで、マイナーループの上端と下端の中点にあるループの中心における磁界Ｈは、記録層１６と安定化層６の磁化の交換結合を示す交換結合磁界H_{ex}として知られている。この実施例で得られた磁気ディスクの場合、H_{ex}は１．４ｋＯｅであることが分かった。一方、比較例の磁気ディスクでは、図５（ｂ）に示すようなヒステリシスマイナーループが得られ、H_{ex}は０．４ｋＯｅであることが分かった。従って、本発明では第１及び第２エンハンス層を、記録層及び磁気結合層の界面、並びに磁気結合層と磁化安定化層との界面にそれぞれ設けたために、記録層と磁化安定化層との交換結合力が著しく向上している。参考として、従来技術の説明の欄で述べた文献に開示された磁気ディスクのH_{ex}は４５０（Ｏｅ）程度であることが報告されている。

【００４８】

さらに、実施例１及び比較例で得られた磁気記録媒体の活性化体積Ｖを測定し、磁気記録媒体の熱安定性の指標となる値であるＫｕ・Ｖ／（ｋ・Ｔ）を求めたところ、実施例１の磁気記録媒体では約７１であったのに対して比較例の磁気記録媒体では６５であった。このことからも、本発明の磁気記録媒体は熱安定性に優れることが分かる。さらに、実施例の磁気記録媒体では、面内磁気記録媒体の高密度記録の可能性を示す指標であるＢｒｔ（＝４πＭｒ・ｔ（式中、Ｍｒは残留磁界、ｔは厚みをそれぞれ示す））は、約４４Ｇμｍであった。

【００４９】

【変形例１】

本発明に従う磁気ディスクでは、記録層と磁化安定化層の間の交換結合をエンハンスするエンハンス層を、記録層及び磁気結合層（非磁性層）の界面、あるいは磁気結合層と磁化安定化層との界面のいずれか一方に設けてもよい。実施例１の変形例として、図２に第１エンハンス層を形成しなかった磁気ディスク３０の構造を示し、図３に第２エンハンス層を形成しなかった磁気ディスク４０の構造を示す。

【００５０】

【変形例２】

実施例１では、磁化安定化層６及び磁気結合層１２をそれぞれ一層ずつ形成したが、それらを２層ずつ形成してもよい。すなわち、ＣｒＭｏ第２下地層４上に、ＣｏＣｒＰｔＢ第１磁化安定化層、第１エンハンス層、Ｒｕ第１磁気結合層、Ｃｏ第２エンハンス層、ＣｏＣｒＰｔＢ第２磁化安定化層、第３エンハンス層、Ｒｕ第２磁気結合層、Ｃｏ第４エンハンス層、ＣｏＣｒＰｔＢ記録層及びカーボン保護層を備える構造にすることができる。ここで、第１及び第２エンハンス層（補助エンハンス層）は、第１及び第２磁化安定化層間の交換結合を増大する作用を有し、第３及び第４エンハンス層は、記録層と第２磁化安定化層間の交換結合を増大する作用を有する。あるいは、図２に示した磁気ディスク３０において、第２エンハンス層１４と記録層１６との間に、第２磁化安定化層、第２磁気結合層及び第４エンハンス層を加えても良い。さらに、図３に示した磁気ディスク４０において、磁気結合層１２と記録層１６との間に、第２磁化安定化層、第４エンハンス層及び第２磁気結合層を加えても良い。

【００５１】

【実施例２】

実施例１と同様のプロセスにより複数枚の磁気ディスクを作製し、各ディスクの保護層上に潤滑剤を塗布した後、それらを磁気記録装置のスピンドルに同軸上に取り付けた。磁気記録装置の概略構成を図８及び図９に示す。図８は磁気記録装置の上面の図であり、図９は、図８の破線Ａ－Ａ’における磁気記録装置６０の断面図である。記録用磁気ヘッドとして、２．１Ｔの高飽和磁束密度を有する軟磁性膜を用いた薄膜磁気ヘッドを用い、再生のために巨大磁気抵抗効果を有するデュアルスピンバルブ型磁気ヘッドを用いた。記録用磁気ヘッド及び再生用磁気ヘッドは一体化されており、図８及び図９では磁気ヘッド５３として示した。この一体型の磁気ヘッド５３は磁気ヘッド用駆動系５４により制御される。複数の磁気ディスク１０は回転駆動系５１のスピンドル５２により同軸回転される。磁気記録装置の磁気ヘッド面と磁気ディスクとの距離は１１ｎｍに保った。この磁気ディスクに４０Ｇｂｉｔｓ／ｉｎｃｈ^2（６．２０Ｇｂｉｔｓ／ｃｍ^2）に相当する信号を記録して磁気ディスクのＳ／Ｎを評価したところ、２５ｄＢの再

生出力が得られた。

【００５２】

磁気記録装置６０の記録安定性を評価するために、磁気記録装置６０を８０℃、湿度８０％の環境下に１００時間置いた。１００時間経過後に、記録した信号を再生して磁気ディスクのＳ／Ｎを測定したところ、２４．３ｄＢの再生出力が得られた。すなわち、上記環境下での記録信号の低下率は３％であった。

【００５３】

【比較例２】

比較例の磁気ディスク５０を実施例２と同様にして磁気記録装置に組み込んだ。この磁気記録装置の記録安定性を評価するために、磁気記録装置６０を８０℃、湿度８０％の環境下に１００時間置いた。１００時間経過後に、記録した信号を再生して磁気ディスクのＳ／Ｎを測定したところ、２２．５ｄＢの再生出力が得られた。すなわち、上記環境下での記録信号の低下率は１０％であった。従って、本発明の磁気ディスクを備える磁気記録装置は記録安定性に関して優れていることが分かる。

【００５４】

【実施例３】

本発明に従う磁気記録媒体の別の具体例の概略構成を図１０に示す。磁気記録媒体７０は、ガラス基板２０上に、第１下地層２、第２下地層４、補助磁性層７８、磁気結合層（非磁性層）１２、記録層１６及び保護層１８を備える。各層は以下のようにＤＣマグネトロンスパッタ装置を用いてスパッタリングにより形成した。

【００５５】

まず、直径２．５ｉｎｃｈ（６．２５ｃｍ）のガラス基板をＤＣマグネトロンスパッタ装置の準備室に装填した。準備室を減圧し、真空度を1×10^{-5}Ｐａにした後、ガラス基板上の水分を除去するためにガラス基板を２００℃で１０分間加熱した。次いで、ガラス基板を、準備室から、1×10^{-5}Ｐａの真空度を有する成膜室に搬送した。成膜室において、ガラス基板を３４０℃まで加熱した。

【００５６】

加熱されたガラス基板２０上に、第１金属下地層２として、ＮｉＡｌ膜を形成した。ターゲットには原子比でＮｉ：Ａｌ＝５０：５０のＮｉＡｌ合金を用いた。ＮｉＡｌ膜の膜厚は５０ｎｍであった。スパッタ時のＡｒガス圧は０．３Ｐａ、投入電力は５００Ｗであった。

【００５７】

第２金属下地層４として、ＣｒＭｏ膜を第１金属下地層２上に膜厚２０ｎｍで形成した。ターゲットにはＭｏ：２７原子％のＣｒＭｏ合金を用いた。成膜条件は、第１金属下地層２の場合と同様にした。

【００５８】

次いで、補助磁性層７８として、ＣｏＰｔ膜を第２金属下地層上に膜厚２ｎｍで形成した。ターゲットにはＰｔ：１７原子％のＣｏＰｔ合金を用いた。スパッタ時の成膜条件として、投入電力は１００Ｗとし、基板とターゲット間の間隔を長くした以外は、第１金属下地層２の場合と同様にした。

【００５９】

次いで、磁気結合層１２として、Ｒｕ膜を補助磁性層７８上に膜厚０．８ｎｍで形成した。ターゲットにはＲｕを用いた。スパッタ時の成膜条件は、補助磁性層７８の場合と同様にした。

【００６０】

記録層１６として、面内方向の磁化を有するＣｏＣｒＰｔＢ膜を磁気結合層上に膜厚１８ｎｍで形成した。ターゲットには$Co_{64}Cr_{20}Pt_{12}B_{4}$合金を用いた。成膜条件は、第１金属下地層２の場合と同様にした。

【００６１】

最後に、ＣｏＣｒＰｔＢ記録層１６上に、保護膜としてのカーボン層を膜厚５ｎｍで形成した。成膜条件は、第１金属下地層２の場合と同様であった。こうして図１０に示した構造の磁気ディスク７０を製造した。

【００６２】

こうして得られた磁気ディスクについて、実施例１と同様に、ＶＳＭにより磁界を印加して外部磁界に対する磁化曲線を観測した。得られた結果を図１１に示

す。このヒステリシスループからわかるように、この実施例で製造された磁気ディスクも、実施例１で製造した磁気ディスクと同様に、正方向の外部磁界を印加して磁化を飽和させた後、外部磁界を低下させてゆくと、外部磁界がゼロになる前に磁化が急激に低下する領域が存在していた。そして、図１１からわかるように、この領域で、磁化曲線がヒステリシスを示すマイナーループを描いていた。図１１の下方にマイナーループの拡大図を示した。このマイナーループから、実施例１で製造した磁気ディスクの場合と同様にして交換結合磁界H_{ex}を求めたところ、交換結合磁界H_{ex}は、１．７ｋＯｅであった。

【００６３】

つぎに、上記プロセスと同様にして複数枚の磁気ディスクを作製し、それぞれの磁気ディスクの保護層上に潤滑剤を塗布した後、それらを実施例２と同様に図８及び図９に示す磁気記録装置に組み込んだ。この磁気記録装置を用いて、実施例２と同様に磁気ディスクに信号を記録して磁気ディスクのＳ／Ｎを評価したところ、２５ｄＢの再生出力が得られた。

【００６４】

次いで、かかる磁気記録装置の記録安定性を評価するために、実施例２の場合と同様に磁気記録装置を８０℃、湿度８０％の環境下に１００時間置いた。１００時間経過後に、記録した信号を再生して磁気ディスクのＳ／Ｎを測定したところ、２４．５ｄＢの再生出力が得られた。すなわち、上記環境下での記録信号の低下率は２％であった。したがって、比較例２の磁気記録装置との比較から、本発明の磁気ディスクを備える磁気記録装置は記録安定性に関して優れていることがわかる。

【００６５】

【変形例３】

実施例３で製造した磁気ディスクの変形例として、図１２に示すように、磁気結合層１２と記録層１６との界面にエンハンス層７９を設けてもよい。エンハンス層７９は、実施例１で作製した磁気ディスクのエンハンス層８と同様の材料を用いて形成することができ、記録層１６と補助磁性層７８との間の交換結合を増大する作用を有する。

【００６６】

【変形例４】

実施例３で製造した磁気ディスクの別の変形例として、図１３に示すように、第２下地層３上に、更に記録層１６の磁化を安定化させるための磁化安定化層８６及び第２磁気結合層８２を設けてもよい。磁化安定化層８６は、実施例１で作製した磁気ディスクの磁化安定化層６と同様の材料を用いることができる。第２磁気結合層８２は、実施例３と同様にＲｕを用いることができる。また、更に別の変形例として、図１３に示した磁気ディスクにおいて、磁化安定化層８６を、実施例１で用いたエンハンス層で置き換えて構成することも可能である。

【００６７】

以上、本発明を実施例により具体的に説明してきたが、本発明はそれらに限定されない。基板、第１及び第２金属下地層、補助磁性層、磁化安定化層、磁気結合層、第１及び第２エンハンス層及び記録層は、実施例で示した材料に限らず、種々の知られた材料で構成することができる。

【００６８】

【発明の効果】

本発明の第１の態様の磁気記録媒体は、エンハンス層の存在により記録層と磁化安定化層の間の交換結合力が著しく向上しているために熱安定に優れる。従って、高密度記録のために微小磁区を形成しても、熱揺らぎが少なく、記録した情報を長期間に渡って安定に保持することができる。また、本発明の第２の態様の磁気記録媒体は、１ｋＯｅ以上の交換結合磁界を有するので、熱安定性に極めて優れ、高密度記録を実現できる。また、本発明の第３の態様の磁気記録媒体は、記録層を形成する強磁性材料よりも磁性原子濃度の高い強磁性材料から形成された補助磁性層により、記録層と補助磁性層との間で強い交換結合力が発生するので、第１の態様の磁気記録媒体よりも簡単な層構成で、第１の態様の磁気記録媒体と同様に熱安定性を高めることができる。

【００６９】

本発明の磁気記録媒体を備える磁気記録装置は、記録安定性に優れ、例えば、４０Ｇｂｉｔｓ／ｉｎｃｈ^2（６．２０Ｇｂｉｔｓ／ｃｍ^2）を超える超高密度

磁気記録の実現を可能にする。

【図面の簡単な説明】

【図１】

実施例１の磁気ディスクの断面構造を示す図である。

【図２】

実施例１の磁気ディスクの変形例の断面構造を示す図である。

【図３】

実施例１の磁気ディスクの別の変形例の断面構造を示す図である。

【図４】

実施例１の磁気ディスクのヒステリシスループ（メジャーループ）を示すグラフである。

【図５】

図４におけるヒステリシスループのマイナーループを示すグラフである。

【図６】

従来の磁気ディスクの構造を示す断面図である。

【図７】

比較例１の磁気ディスクの断面構造を示す図である。

【図８】

本発明の実施例２に従う磁気記録装置の一例を上方から見た概略構成図である。

【図９】

図８に示す磁気記録装置のＡ－Ａ’方向の断面図である。

【図１０】

本発明の実施例３で製造した磁気ディスクの概略断面図である。

【図１１】

図１０に示す磁気ディスクのヒステリシスループ（メジャーループ）と、ヒステリシスループのマイナーループの拡大図を示すグラフである。

【図１２】

本発明の実施例３に従う磁気ディスクの変形例の概略断面図である。

【図１３】

本発明の実施例３に従う磁気ディスクの別の変形例の概略断面図である。

【符号の説明】

２　第１金属下地層

４　第２金属下地層

６　磁化安定化層

８　第１エンハンス層

１０　磁気ディスク

１２　磁気結合層

１４　第１エンハンス層

１６　記録層

２０　基板

５２　スピンドル

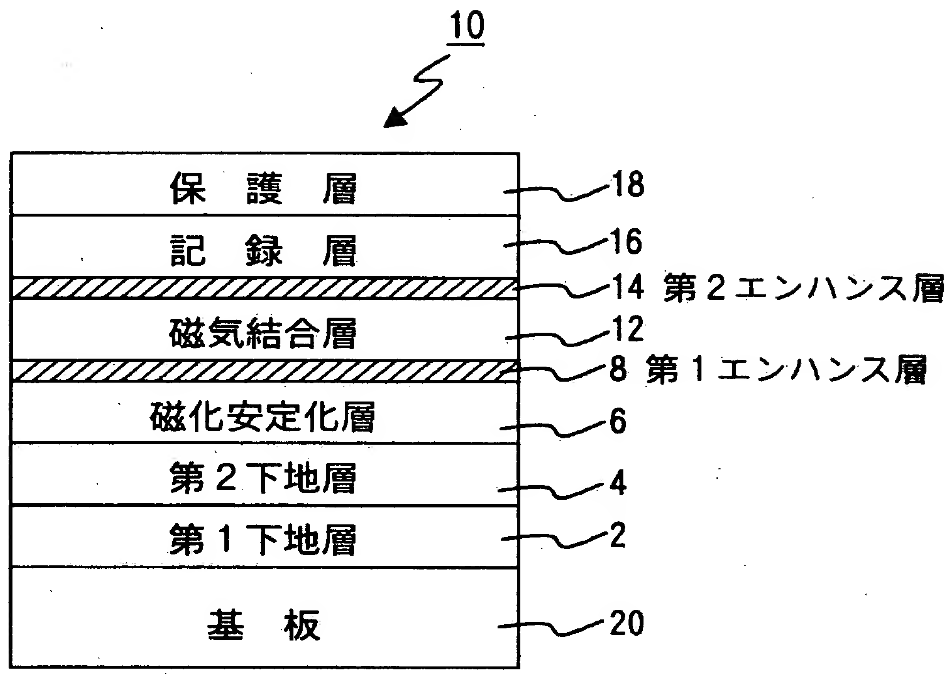
５３　磁気ヘッド

６０　磁気記録装置

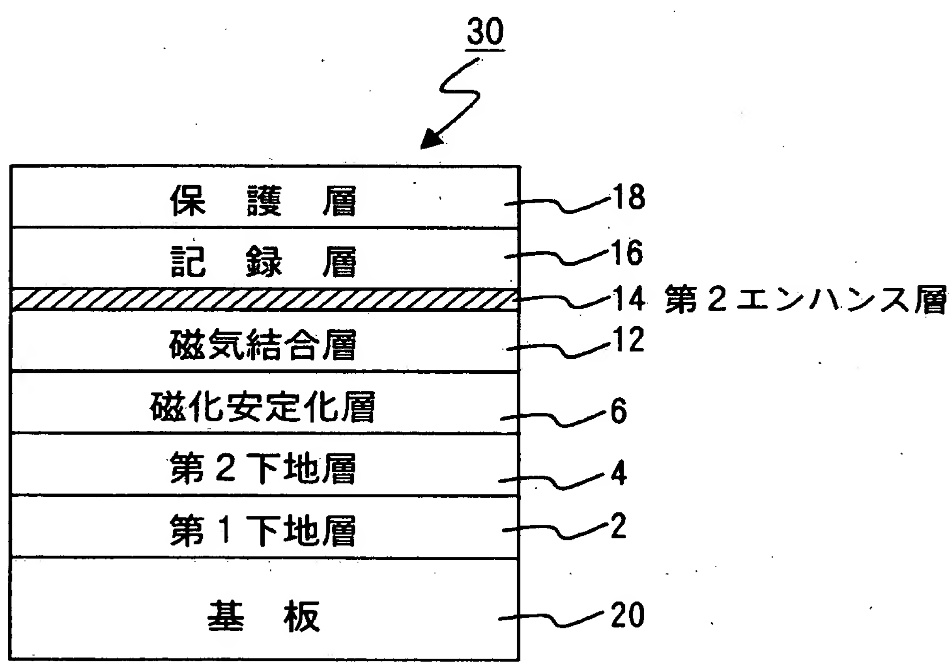
７８　補助磁性層

【書類名】　図面

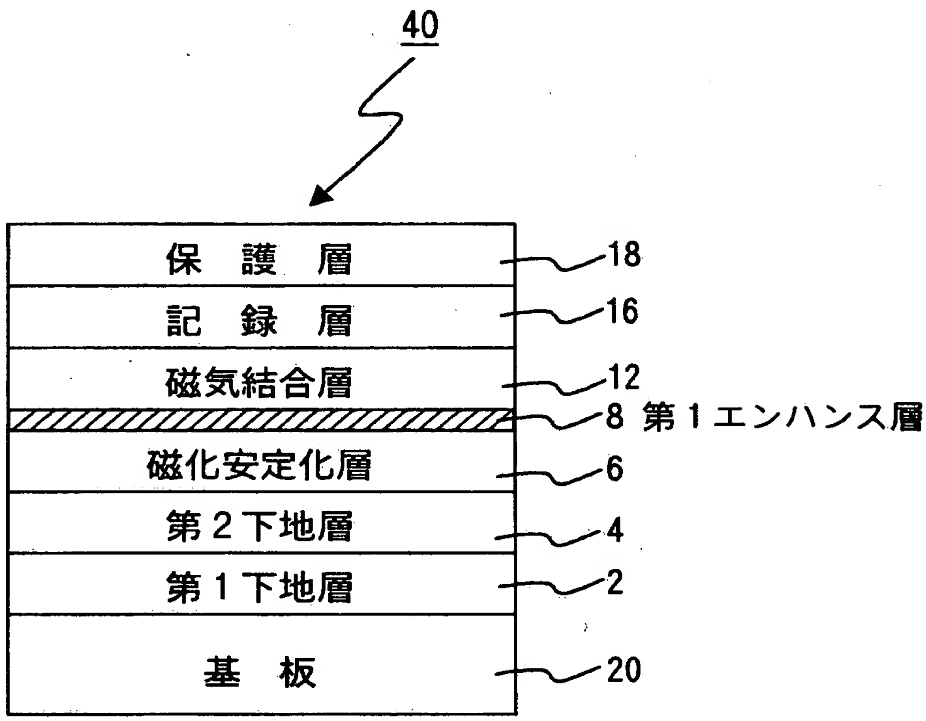
【図１】


10
保護層
18
記録層
16
14 第２エンハンス層
磁気結合層
12
8 第１エンハンス層
磁化安定化層
6
第２下地層
4
第１下地層
2
基板
20

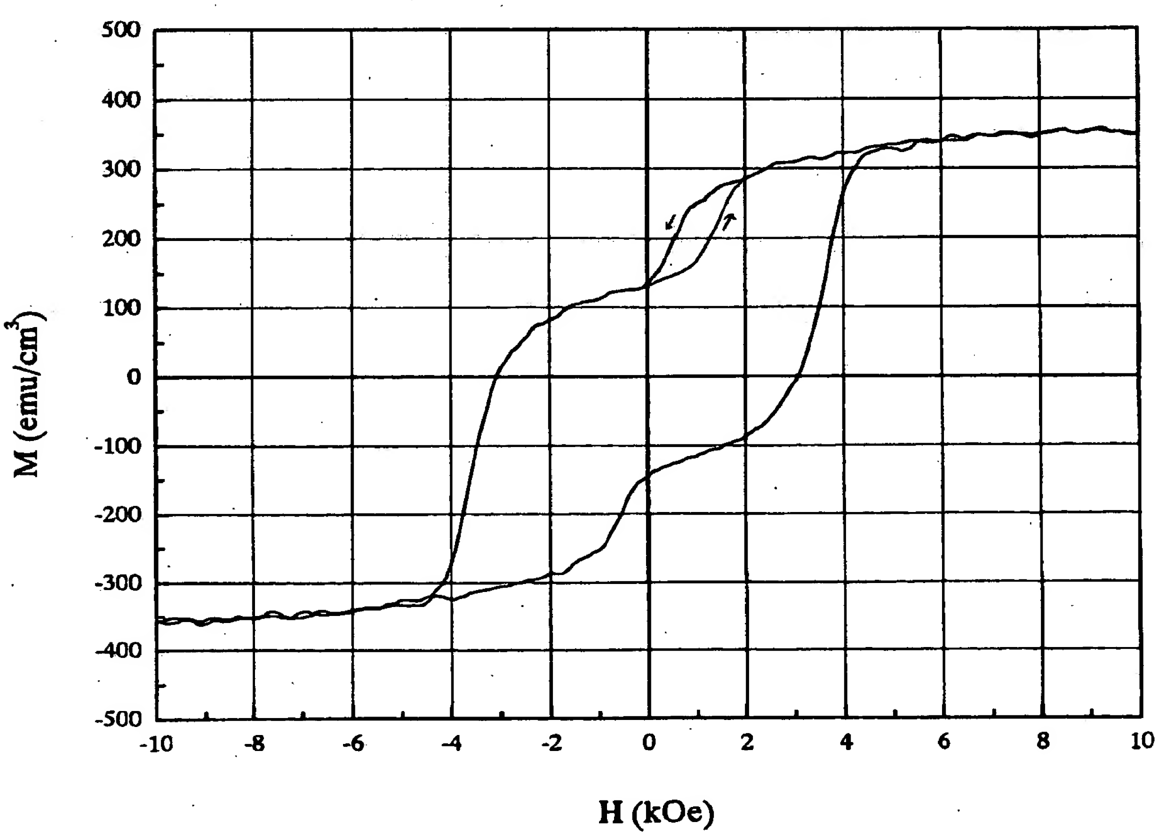
【図２】


30
保護層
18
記録層
16
14 第２エンハンス層
磁気結合層
12
磁化安定化層
6
第２下地層
4
第１下地層
2
基板
20

【図３】

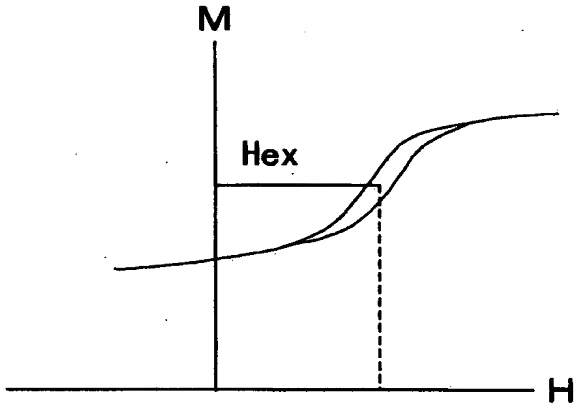

40
保　護　層
18
記　録　層
16
磁気結合層
12
8 第１エンハンス層
磁化安定化層
6
第２下地層
4
第１下地層
2
基　板
20

【図４】

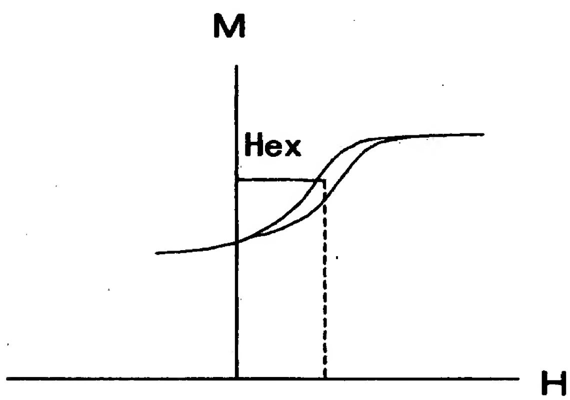

M (emu/cm3)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-10
-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)

【図５】

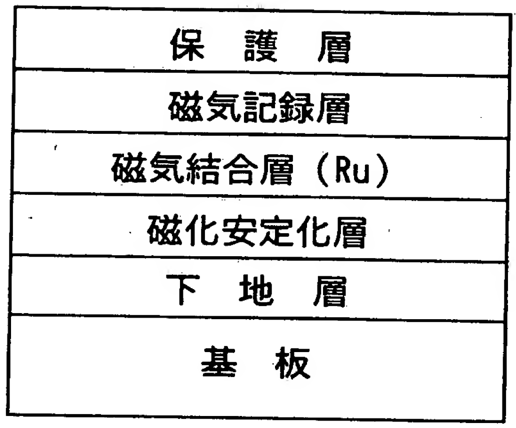
(a)



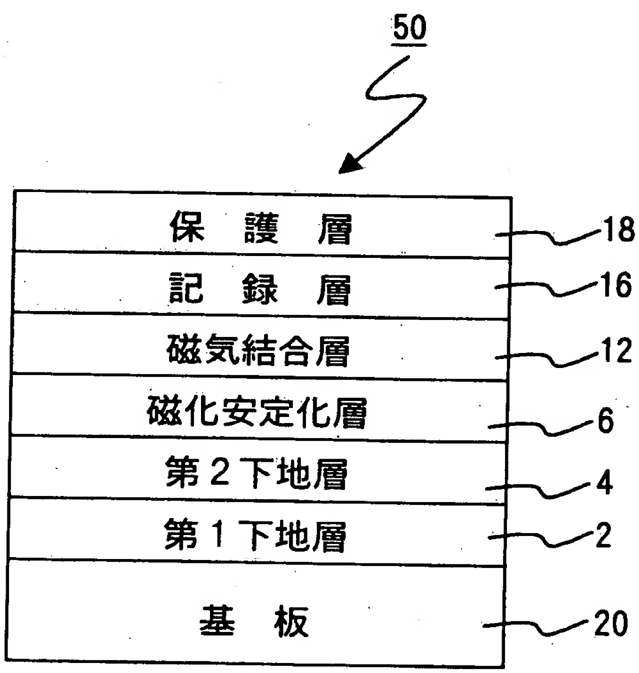
(b)



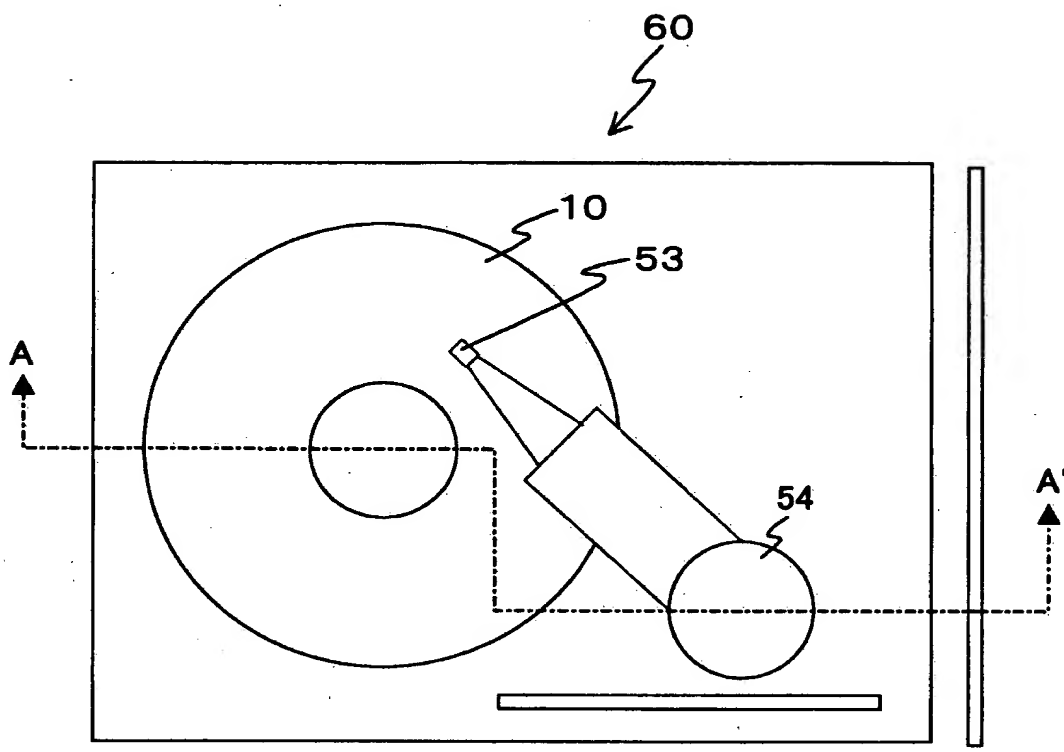
【図６】


保　護　層
磁気記録層
磁気結合層（Ru）
磁化安定化層
下　地　層
基　板

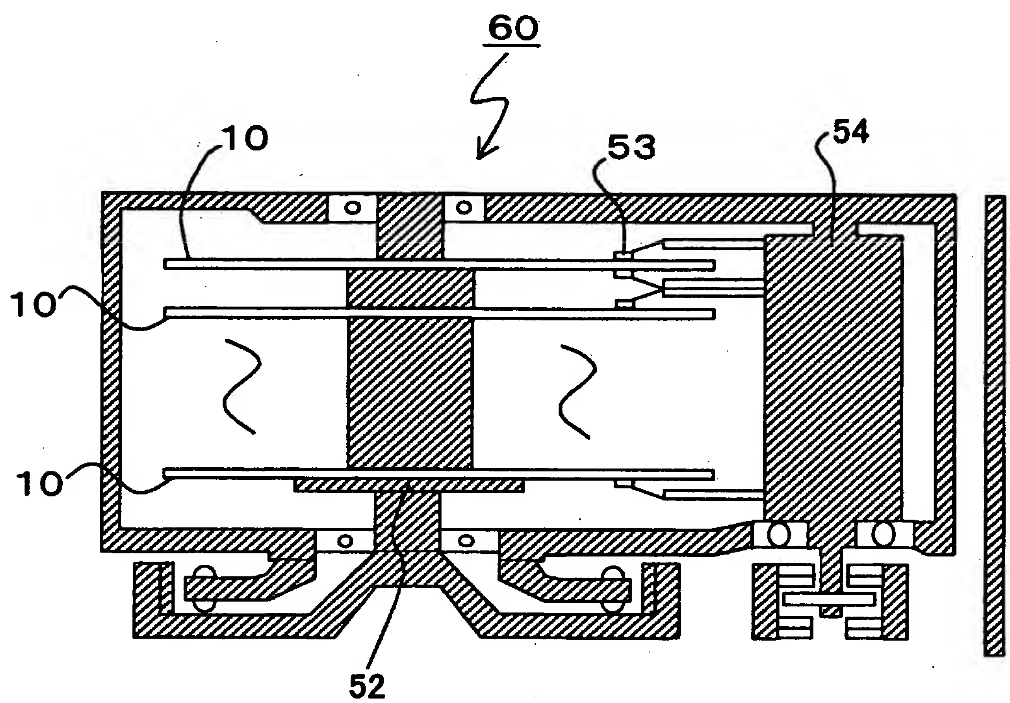
【図７】


50
保　護　層
18
記　録　層
16
磁気結合層
12
磁化安定化層
6
第２下地層
4
第１下地層
2
基　板
20

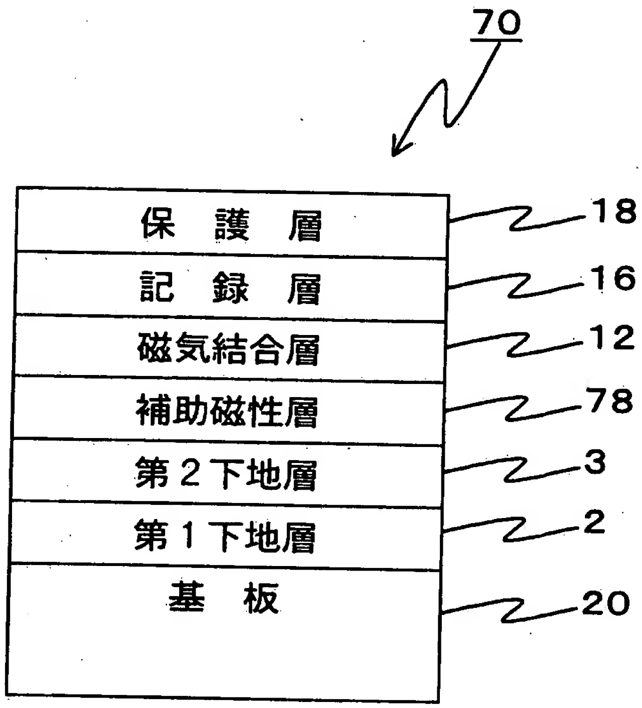
【図８】



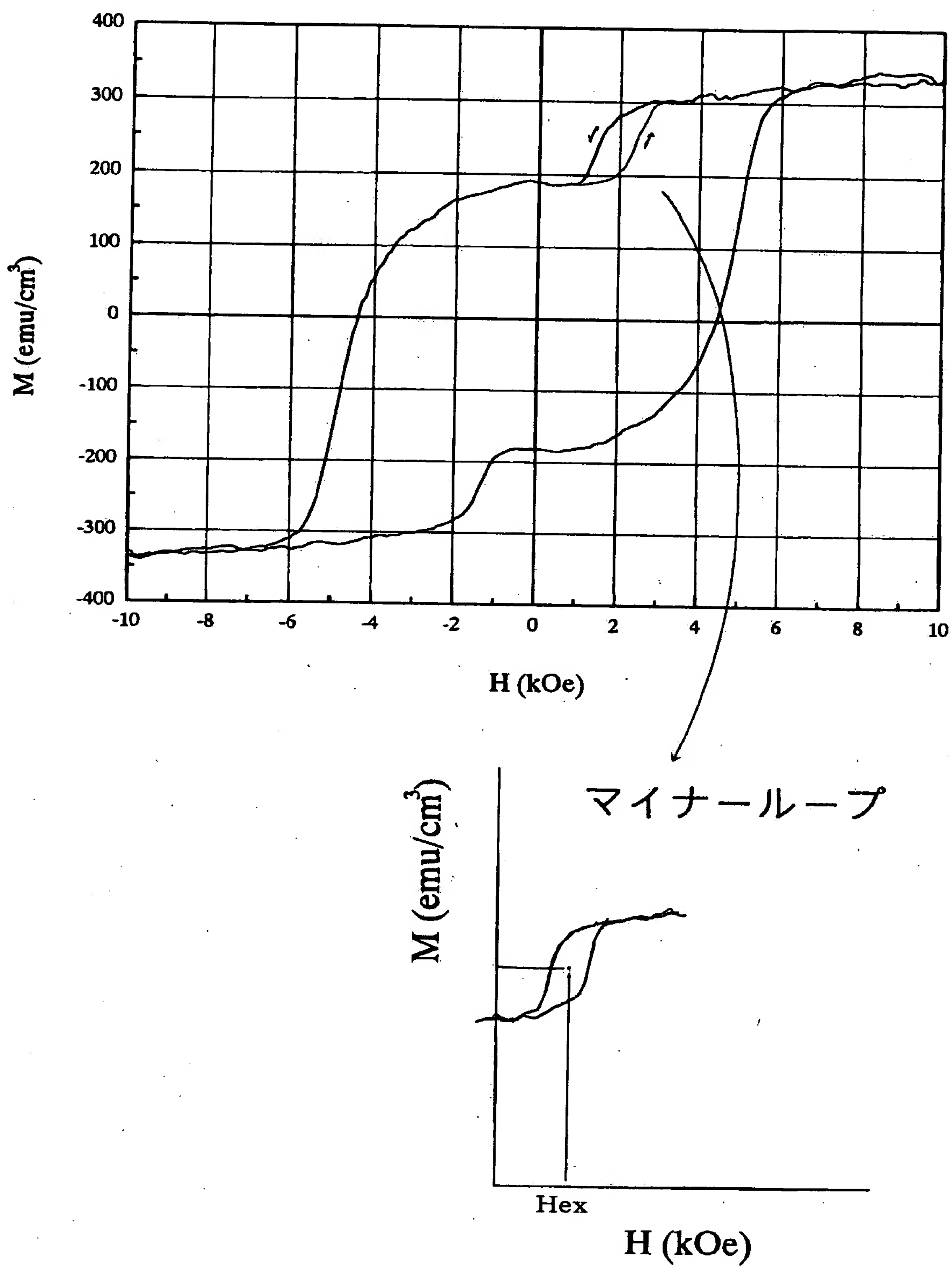
【図９】



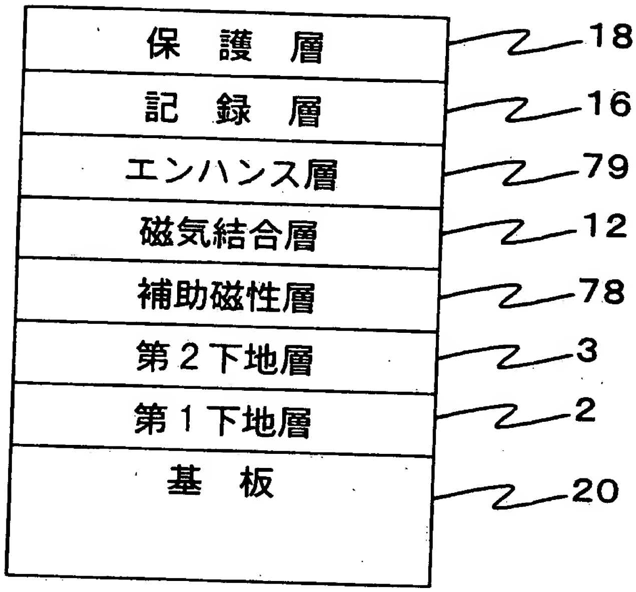
【図１０】



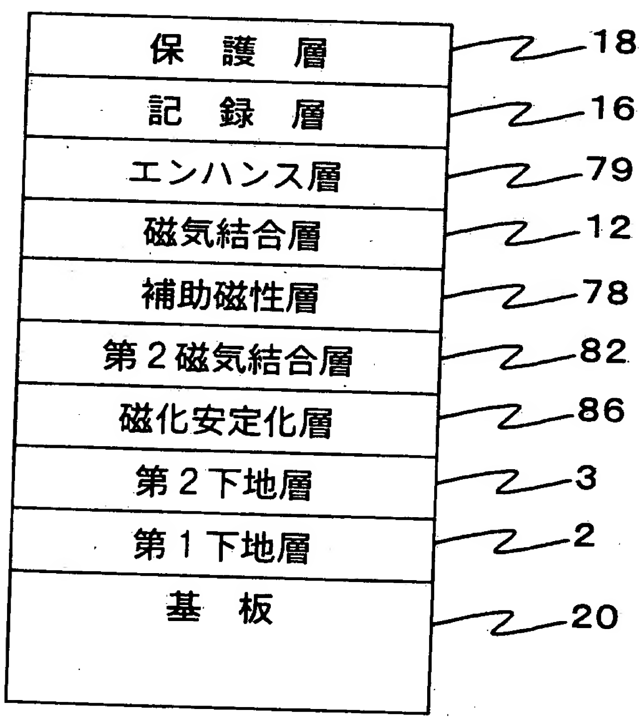
【図１１】


400
300
200
100
0
-100
-200
-300
-400
M (emu/cm3)
-10
-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)
マイナーループ
M (emu/cm3)
Hex
H (kOe)

【図１２】


保護層
記録層
エンハンス層
磁気結合層
補助磁性層
第２下地層
第１下地層
基板
18
16
79
12
78
3
2
20

【図１３】


保護層
記録層
エンハンス層
磁気結合層
補助磁性層
第２磁気結合層
磁化安定化層
第２下地層
第１下地層
基板
18
16
79
12
78
82
86
3
2
20

【書類名】　要約書

【要約】

【課題】　熱安定性に優れた高密度記録用磁気記録媒体を提供する。

【解決手段】　面内磁気記録媒体１０は、基板２０上に、ＮｉＡｌ第１下地層２、ＣｒＭｏ第２下地層４、ＣｏＣｒＰｔＢ磁化安定化層６、Ｒｕ磁気結合層１２、Ｃｏ第２エンハンス層８、ＣｏＣｒＰｔＢ記録層１６及びカーボン保護層１８を備える。磁化安定化層６は記録層１６の磁化を安定化させ、磁気結合層１２は記録層１６と磁化安定化層６の交換結合力をもたらす。磁気結合層１２及び磁化安定化層６の界面並びに磁気結合層１２及び記録層１６の界面に、それぞれ、Ｃｏから構成された第１エンハンス層８及び第２エンハンス層１４を備えることにより、交換結合が著しく向上する。これにより、磁気記録媒体の熱安定性に優れ、長期間に渡る記録安定性に優れた磁気記録装置を提供することができる。

【選択図】　図１

出　願　人　履　歴　情　報

識別番号　　　〔０００００５８１０〕

１．変更年月日　　１９９０年　８月２９日
　　［変更理由］　新規登録
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　　　氏　名　　日立マクセル株式会社

TRANSLATOR'S VERIFICATION

I hereby declare and state that I am knowledgeable of each of the Japanese and English languages and that I made and reviewed the attached translation of the certified copy of Japanese Patent Application No. 2001-054254, filed on February 28, 2001 from the Japanese language into the English language, and that I believe my attached translation to be accurate, true and correct to the best of my knowledge and ability.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of this application or any patent issued thereon.

Date: February 3, 2004

Kiyoko Ishimura
(Signature)

Kiyoko Ishimura
(Typed name)

JAPAN PATENT OFFICE

This is to certify that the annexed is a true copy of the following application as filed with this Office.

Date of Application: February 28, 2001
Application Number: 2001-054254
Applicant(s): HITACHI MAXELL, LTD.

September 14, 2001
Commissioner, Japan Patent Office
Kozo OIKAWA

Certificate Issuance No. 2001-3085250

[Title of the Document]	Patent Application
[Reference Number]	HM0106
[Filing Date]	February 28, 2001
[Attention]	To Commissioner, Patent Office
[IPC]	G11B 11/10
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[Agent of the Applicant]

[Identified Number]	100099793
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[Telephone]	03-5362-3180

[Indication of charge]

[Serial number for pre-paid]	057521
[Amount of payment]	21,000yen

[List of filing documents]

[Name of Document]	Specification	1
[Name of Document]	Drawing	1
[Name of Document]	Abstract	1
[Number of General Power of Attorney]	9500734	

[Necessity of the proof] yes

INFORMATION ON APPLICANT'S HISTORY

Identified Number [000005810]

1. Date of change	August 29, 1990
[Reason for change]	New Registration
Address	1-88, Ushitora 1-chome, Ibaraki-shi, Osaka
Name	HITACHI MAXELL, LTD.

[TITLE OF THE DOCUMENT] Specification

[TITLE OF THE INVENTION] MAGNETIC RECORDING MEDIUM AND MAGNETIC RECORDING APPARATUS

[CLAIMS]

[Claim 1] A magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer;

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer; and

an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases exchange coupling between the recording layer and the magnetization-stabilizing layer.

[Claim 2] The information-recording medium according to claim 1, characterized in that the enhancing layer is formed of one selected from the group consisting of Co, Ni, Fe, and CoNiFe alloy.

[Claim 3] The information-recording medium according to claim 1, characterized in that the enhancing layer is

formed of an alloy containing a transition metal and Co, Ni or Fe.

[Claim 4] The magnetic recording medium according to claim 1, characterized in that:

the recording layer or the magnetization-stabilizing layer is formed of a material containing Co, Ni or Fe; and

the enhancing layer is formed of a material containing Co, Ni or Fe at a concentration which is higher than a concentration in the recording layer or the magnetization-stabilizing layer.

[Claim 5] The magnetic recording medium according to any one of claims 1 to 4, characterized in that the enhancing layer includes a first enhancing layer which exists between the non-magnetic layer and the magnetization-stabilizing layer, and a second enhancing layer which exists between the non-magnetic layer and the recording layer.

[Claim 6] The magnetic recording medium according to any one of claims 1 to 5, characterized in that the enhancing layer has a film thickness of 0.2 to 2 nm.

[Claim 7] The magnetic recording medium according to any one of claims 1 to 6, characterized in that the non-magnetic layer is formed of Ru.

[Claim 8] The magnetic recording medium according to any one of claims 1 to 7, characterized in that:

the magnetization-stabilizing layer includes a first magnetization-stabilizing layer and a second magnetization-stabilizing layer, and the non-magnetic layer includes a first non-magnetic layer and a second non-magnetic layer, the first non-magnetic layer being formed between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer, and the second non-magnetic layer being formed between the second magnetization-stabilizing layer and the recording layer; and

the enhancing layer exists at least at one of positions between the second non-magnetic layer and the recording layer and between the second non-magnetic layer and the second magnetization-stabilizing layer, and comprises an auxiliary enhancing layer which is provided at least at one of positions between the first magnetization-stabilizing layer and the first non-magnetic layer and between the first non-magnetic layer and the second magnetization-stabilizing layer, and which increases exchange coupling between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer.

[Claim 9] The magnetic recording medium according to claim 8, characterized in that the auxiliary enhancing layer includes a first auxiliary enhancing layer which is

formed between the first non-magnetic layer and the first magnetization-stabilizing layer, and a second auxiliary enhancing layer which is formed between the first non-magnetic layer and the second magnetization-stabilizing layer.

[Claim 10] The magnetic recording medium according to any one of claims 1 to 9, characterized by further comprising a substrate on which an underlying base layer is formed, wherein the magnetization-stabilizing layer is provided on the underlying base layer.

[Claim 11] A magnetic recording medium characterized by comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer; and

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer,

wherein a magnetization curve of the magnetic recording medium with respect to an external magnetic field exhibits a hysteresis loop, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization is saturated,

exists in a positive area of the external magnetic field, and an exchange coupling magnetic field, which is determined from the magnetization curve, is not less than 1 kOe.

[Claim 12] The magnetic recording medium according to claim 11, characterized by further including an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases exchange coupling between the recording layer and the magnetization-stabilizing layer.

[Claim 13] The magnetic recording medium according to claim 11 or 12, characterized in that the recording layer and the magnetization-stabilizing layer include Co, Ni or Fe, and the enhancing layer is formed of Co, Ni or Fe.

[Claim 14] The magnetic recording medium according to claim 11, characterized in that the magnetization-stabilizing layer is formed of a ferromagnetic material having a high magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer.

[Claim 15] The magnetic recording medium according to claim 14, characterized in that the magnetization-stabilizing layer is formed of one selected from the group consisting of Co, Ni, Fe, and CoNiFe alloy.

[Claim 16] The information-recording medium according

to claim 14, characterized in that the magnetization-stabilizing layer is formed of an alloy containing a transition metal and Co, Ni or Fe.

[Claim 17] The information-recording medium according to claim 15 or 16, characterized in that the recording layer is formed of a material which includes Co, Ni or Fe.

[Claim 18] A magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

an auxiliary magnetic layer which is formed of a ferromagnetic material having a high magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer; and

a non-magnetic layer which is formed between the recording layer and the auxiliary magnetic layer.

[Claim 19] The information-recording medium according to claim 18, characterized in that the auxiliary magnetic layer is formed of one selected from the group consisting of Co, Ni, Fe, and CoNiFe alloy.

[Claim 20] The information-recording medium according to claim 18, characterized in that the auxiliary magnetic layer is formed of an alloy containing a transition metal and Co, Ni or Fe.

[Claim 21] The magnetic recording medium according to claim 19 or 20, characterized in that the recording layer

is formed of a material containing Co, Ni or Fe.

[Claim 22] The magnetic recording medium according to any one of claims 18 to 21, characterized by further comprising an enhancing layer which is provided between the recording layer and the non-magnetic layer, and which increases exchange coupling between the auxiliary magnetic layer and the recording layer.

[Claim 23] The magnetic recording medium according to any one of claims 18 to 22, characterized in that the non-magnetic layer is formed of Ru.

[Claim 24] The magnetic recording medium according to any one of claims 18 to 23, characterized in that the auxiliary magnetic layer has a film thickness of 1 to 5 nm.

[Claim 25] The magnetic recording medium according to any one of claims 18 to 24, characterized by further comprising a substrate, a second non-magnetic layer, and a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer,

wherein the second non-magnetic layer is positioned between the substrate and the auxiliary magnetic layer on a side which is near to the auxiliary magnetic layer.

[Claim 26] The magnetic recording medium according to any one of claims 18 to 24, characterized by further comprising a substrate, a second non-magnetic layer, and a

second auxiliary magnetic layer,

wherein the second non-magnetic layer is positioned between the substrate and the auxiliary magnetic layer on a side which is near to the auxiliary magnetic layer.

[Claim 27] The magnetic recording medium according to claim 25 or 26, characterized by further comprising an underlying base layer which is formed on the substrate.

[Claim 28] The magnetic recording medium according to any one of claims 1, 11 and 18, characterized in that the recording layer has a magnetization in the in-plane direction.

[Claim 29] A magnetic recording apparatus comprising:

the magnetic recording medium according to any one of claims 1, 11 and 18;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD TO WHICH THE INVENTION BELONGS]

The present invention relates to a magnetic recording medium and a magnetic recording apparatus. In particular, the present invention relates to an in-plane magnetic recording medium which is excellent in thermal stability

and which is preferable for high density recording, and a magnetic recording apparatus which is installed with the in-plane magnetic recording medium.

[0002]

[PRIOR ART]

Accompanying with the recent progress of the advanced information society, the multimedia, with which not only the character information but also the voice and image information can be processed at a high speed, are popularized. A magnetic recording apparatus, which is installed to a computer or the like, is known as one of the multimedia. At present, the development is advanced in order that the magnetic recording apparatus is miniaturized while improving the recording density of such a magnetic recording apparatus.

[0003]

A typical magnetic recording apparatus includes a plurality of magnetic disks which are rotatably installed onto a spindle. Each of the magnetic disks comprises a substrate and a magnetic film formed thereon. Information is recorded by forming a magnetic domain having a specified magnetization direction in the magnetic film.

[0004]

In order to realize the high density recording with the magnetic recording apparatus as described above, it is

demanded that the diameter of grains for constructing the magnetic film is made fine and minute and the interaction between the respective grains is lowered. However, a problem arises such that the thermal stability of the grains is lowered if the grain diameter is made fine and minute and the interaction between the grains is lowered.

[0005]

The known technique for improving the thermal stability of the magnetic disk, especially a magnetic disk having magnetization in the in-plane direction include a method in which a so-called keeper layer having soft magnetization is provided as an underlying base layer for a recording layer, and a method in which a layer having magnetization in a direction opposite to that of magnetization of a recording layer is provided. As one of the latter method, a technique is disclosed in a literature of E. N. Abarra et al. (E. N. Abarra et al., TECHNICAL REPORT OF IEICE. MR2000-34 (2000-10)) as shown in Fig. 6, in which the thermal stability is improved by forming an Ru thin film as a magnetic coupling layer between a recording layer of CoCrPtB and a magnetization-stabilizing layer of CoCrPtB of a magnetic disk. In the structure of the magnetic disk shown in Fig. 6, when the Ru layer having a thickness of about 0.5 to 1 nm is allowed to intervene as the magnetic coupling layer between the recording layer and

the magnetization-stabilizing layer, the exchange coupling is effected in an antiferromagnetic manner between the recording layer and the magnetization-stabilizing layer. Therefore, the layers have antiparallel magnetization, and hence the magnetization of the recording layer is stabilized by the magnetization-stabilizing layer. It is described in this literature that the antiferromagnetic exchange coupling effected by the Ru layer further thermally stabilizes the magnetization of the recording layer, making it possible to improve the recording and reproduction characteristics of the magnetic disk.

[0006]

[PROBLEM TO BE SOLVED BY THE INVENTION]

However, in order to realize further advanced high density recording with a magnetic recording apparatus, it is required to provide a magnetic recording apparatus which is provided with a magnetic disk that is more excellent in thermal stability than the magnetic disk disclosed in the literature described above.

[0007]

A first object of the present invention is to provide a magnetic recording medium, especially an in-plane magnetic recording medium which is excellent in thermal stability, and a magnetic recording apparatus provided with the same.

[0008]

A second object of the present invention is to provide a magnetic recording apparatus which is excellent in stability (recording stability) of recorded information.

[0009]

A third object of the present invention is to provide a magnetic recording medium which is suitable for high density recording, and a magnetic recording apparatus installed with the same.

[0010]

[MEANS FOR SOLVING THE PROBLEM]

According to a first aspect of the present invention, there is provided a magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer;

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer; and

an enhancing layer which exists at least one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer, and which increases

magnetization-stabilizing layer is as follows. In the case of the conventional type magnetic disk shown in Fig. 6, the recording layer of CoCrPtB and the magnetization-stabilizing layer of CoCrPtB are stacked with the Ru layer intervening therebetween. In this case, the recording layer and the magnetization-stabilizing layer effect the exchange coupling via the Ru atom layer. It is considered that the exchange coupling is effected on the basis of the fact that the electron orbits are coupled between the Co atoms in the recording layer and the magnetization-stabilizing layer via the Ru atoms. Such a coupling is also found, for example, in the coupling in an artificial lattice of a GMR head.

[0013]

However, when the interface between the recording layer and the Ru layer is observed, then the crystal grains in the recording layer are rich in Co, and the grain boundary therebetween has a Cr-rich composition, because the recording layer is composed of CoCrPtB. As a result, it is considered that the Cr atoms, which amount is larger than that of the Co atoms, are exposed on the surface of the recording layer on the side of the Ru layer. The magnetization-stabilizing layer is also composed of the CoCr alloy (CoCrPtB) in the same manner as the recording layer. Therefore, it is considered that a large amount of

exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0011]

As a result of repeated investigations performed by the present inventors in order to further improve the magnetic disk having the conventional type structure shown in Fig. 6, it has been found out that the exchange coupling between the recording layer and the magnetization-stabilizing layer can be remarkably improved by intervening a several-atoms-layered Co layer at an interface between the Ru layer (non-magnetic layer) and the recording layer and/or an interface between the Ru layer (non-magnetic layer) and the magnetization-stabilizing layer. The layer to be intervened at the interface is not limited to Co, but may be constructed with a variety of substances capable of improving the exchange coupling between the recording layer and the magnetization-stabilizing layer as described later on. In this specification, this layer is referred to as "enhancing layer", which functions to enhance the exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0012]

According to the knowledge of the present inventors, the reason why the enhancing layer successfully improves the exchange coupling between the recording layer and the

Cr atoms for covering Co are exposed on the surface of the magnetization-stabilizing layer on the side of the Ru layer. It is assumed that the Cr atom layers inhibit the electron coupling between the Co atoms in the recording layer and the magnetization-stabilizing layer via the Ru atoms as described above, thereby weakening the exchange coupling between the recording layer and the magnetization-stabilizing layer. In the present invention, the recording layer or the magnetization-stabilizing layer, on which the Cr atoms are exposed on the surface, is covered with the enhancing layer. Accordingly, it is considered that the exchange coupling between the recording layer and the magnetization-stabilizing layer is improved by the exchange coupling between the atoms such as Co for constructing the enhancing layer.

[0014]

The enhancing layer may be formed of Co, Ni or Fe, or a CoNiFe alloy. Alternatively, the enhancing layer may be formed of an alloy containing Co, Ni, or Fe and a transition metal, especially a noble metal such as Pt, Au, Ag, Cu, and Pd. The atom or the alloy as described above functions to make the coupling electronically via the non-magnetic layer so that the exchange coupling magnetic field is increased. Alternatively, when the recording layer or the magnetization-stabilizing layer is formed of a material

containing Co, Ni, or Fe, it is also effective to form the enhancing layer with a material containing Co, Ni, or Fe at a higher concentration than a concentration in the recording layer or the magnetization-stabilizing layer.

[0015]

The enhancing layer may exist at least at one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer. However, it is desirable that the enhancing layer includes a first enhancing layer which exists between the non-magnetic layer and the magnetization-stabilizing layer and a second enhancing layer which exists between the non-magnetic layer and the recording layer in order to further enhance the exchange coupling between the recording layer and the magnetization-stabilizing layer.

[0016]

The magnetization-stabilizing layer may include a first magnetization-stabilizing layer and a second magnetization-stabilizing layer, the non-magnetic layer may include a first non-magnetic layer and a second non-magnetic layer, the first non-magnetic layer may be formed between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer, and the second non-magnetic layer may be formed between the second

magnetization-stabilizing layer and the recording layer. In this arrangement, the enhancing layer may exist at least at one of positions between the second non-magnetic layer and the recording layer and between the second non-magnetic layer and the second magnetization-stabilizing layer, and may include an auxiliary enhancing layer which exists at least at one of positions between the first magnetization-stabilizing layer and the first non-magnetic layer and between the first non-magnetic layer and the second magnetization-stabilizing layer, and which increases exchange coupling between the first magnetization-stabilizing layer and the second magnetization-stabilizing layer. Further, the auxiliary enhancing layer may include a first auxiliary enhancing layer which is formed between the first non-magnetic layer and the first magnetization-stabilizing layer, and a second auxiliary enhancing layer which is formed between the first non-magnetic layer and the second magnetization-stabilizing layer. The auxiliary enhancing layer may be composed of the same material as that for the enhancing layer described above.

[0017]

It is desirable that the enhancing layer (as well as the auxiliary enhancing layer) has a film thickness of 0.2 to 3 nm, preferably 0.2 to 2 nm, in order to obtain a significant enhancing effect for the exchange coupling.

[0018]

The non-magnetic layer may be formed of Ru. However, there is no limitation thereto. It is possible to use a transition metal such as Rh, Ir, Hf, Cu, Cr, Ag, Au, Re, Mo, Nb, W, Ta, and V, and a non-magnetic alloy based on the CoCr system such as CoCrRu. Ru is preferred in order to further enhance the exchange coupling. In the present invention, the non-magnetic layer has a function to magnetically couple the recording layer and the magnetization-stabilizing layer. Therefore, the non-magnetic layer is also referred to as "magnetic coupling layer".

[0019]

In the magnetic recording medium of the present invention, the recording layer may be crystalline, and the crystalline phase may be composed of an alloy principally containing cobalt (Co). The Co alloy may contain Co as well as Cr, Pt, Ta, Nb, Ti, Si, B, P, Pd, V, Tb, Gd, Sm, Nd, Dy, Ho or Eu, or a combination thereof.

[0020]

When the recording layer contains chromium (Cr), it is possible to form a segregation portion of Cr at the grain boundary or in the vicinity of the grain boundary between the crystal grains (magnetic grains) principally containing Co. When the recording layer further contains Ta, Nb, Ti,

B or P, or a combination of these elements, the segregation of Cr is facilitated. Owing to the segregation, it is possible to reduce the magnetic interaction between the magnetic grains, and it is possible to decrease the number of magnetic grains for constructing the unit of inversion of magnetization. Therefore, it is possible to provide the magnetic recording medium which is strong against the thermal fluctuation regardless of the minute unit of inversion of magnetization, when the enhancing layer of the present invention is used in combination with the recording layer containing the foregoing additive in the CoCr alloy.

[0021]

The magnetic recording medium of the present invention may further comprise a substrate, and an underlying base layer which is formed on the substrate. In this arrangement, the magnetic recording medium may comprise the magnetization-stabilizing layer on the underlying base layer. The substrate may be formed of glass or plastic such as polycarbonate. The underlying base layer may be formed of Cr or Ni, or, Cr alloy or Ni alloy. The Cr alloy or the Ni alloy may contain Cr, Ti, Ta, V, Ru, W, Mo, Nb, Ni, Zr, or Al other than the base element. The underlying base layer is used in order to control the crystalline orientation and the lattice constant of the magnetic layer. The underlying base layer may be also used as a single

layer or a plurality of layers.

[0022]

According to a second aspect of the present invention, there is provided a magnetic recording medium characterized by comprising:

a recording layer which is formed of a ferromagnetic material;

a magnetization-stabilizing layer which is formed of a ferromagnetic material and which stabilizes magnetization of the recording layer; and

a non-magnetic layer which exists between the recording layer and the magnetization-stabilizing layer,

wherein a magnetization curve of the magnetic recording medium with respect to an external magnetic field exhibits a hysteresis loop, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization is saturated, exists in a positive area of the external magnetic field, and an exchange coupling magnetic field, which is determined from the magnetization curve, is not less than 1 kOe.

[0023]

The magnetic recording medium having the magnetization-stabilizing layer of the present invention

has a magnetic characteristic which is represented by a hysteresis loop as depicted by a magnetization curve as shown in Fig. 4. In the hysteresis loop shown in Fig. 4, a point, at which a rate of change of magnetization with respect to the external magnetic field exhibits a local maximum when the external magnetic field is lowered after magnetization of the magnetic recording medium is saturated, exists in an area of positive magnetic field. It is considered that the sudden change of rate of change of magnetization is caused for the following reason. That is, when the magnetization of the magnetic recording medium is saturated, both of the magnetizations of the recording layer and the magnetization-stabilizing layer are parallel, and the magnetization of the magnetization-stabilizing layer is inverted in the area in which the rate of change of magnetization exhibits the local maximum as the external magnetic field is lowered, thereby stabilizing the magnetization of the recording layer. In this area, a minor hysteresis loop as shown in Fig. 4 may be observed. The minor hysteresis loop is shown in Fig. 5. The exchange coupling magnetic field H_{ex}, which is determined from the central point of the minor hysteresis loop, is not less than 1 kOe, preferably not less than 1.5 kOe, which is remarkably larger than that of the conventional type magnetic recording medium shown in Fig. 6. Therefore, it

is appreciated that the magnetic recording medium of the present invention is excellent in thermal stability.

[0024]

In order to generate the large exchange coupling magnetic field H_{ex}, the enhancing layer may be provided at least at one of positions between the non-magnetic layer and the recording layer and between the non-magnetic layer and the magnetization-stabilizing layer.

[0025]

Alternatively, the large exchange coupling magnetic field H_{ex} can be generated by forming the magnetization-stabilizing layer of a ferromagnetic material having a higher magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer. As such a ferromagnetic material, the same material as the material which may be used for the above-mentioned enhancing layer is preferred. For example, when the recording layer is formed of a ferromagnetic material containing Co, Ni, or Fe, the magnetization-stabilizing layer may be formed of a ferromagnetic material containing Co, Ni, or Fe at a higher concentration as compared with the recording layer. The auxiliary magnetic layer may be also formed of a metal simple substance such as Co, Ni, or Fe, or CoNiFe alloy. Alternatively, the auxiliary magnetic layer may be formed of an alloy containing Co, Ni, or Fe

and a transition metal, especially a noble metal such as Pt, Au, Ag, Cu, and Pd. As described above, in the magnetic recording medium of the second aspect, when the magnetization-stabilizing layer is formed of a ferromagnetic material having a higher magnetic atom concentration as compared with the recording layer, the magnetization-stabilizing layer exhibits a strong exchange coupling force between the magnetization-stabilizing layer and the recording layer, in the same manner as in the case of the auxiliary magnetic layer of the magnetic recording medium of the third aspect which will be described later on. Therefore, it is possible to stabilize the magnetization of the recording layer. Namely, the magnetization-stabilizing layer, which is formed of a ferromagnetic material having a higher magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer, has the same function as that of the auxiliary magnetic layer of the magnetic recording medium of the third aspect. The magnetization-stabilizing layer in the magnetic recording medium of the second aspect of the present invention is a concept which includes the auxiliary magnetic layer of the magnetic recording medium of the third aspect.

[0026]

According to a third aspect of the present invention,

there is provided a magnetic recording medium comprising:

a recording layer which is formed of a ferromagnetic material;

an auxiliary magnetic layer which is formed of a ferromagnetic material having a high magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer; and

a non-magnetic layer which is formed between the recording layer and the auxiliary magnetic layer.

[0027] In the magnetic recording medium according to the third aspect of the present invention, an auxiliary magnetic layer, which effects exchange coupling with the recording layer via the non-magnetic layer, is formed with a ferromagnetic material which has a high magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer. As such a ferromagnetic material, the same ferromagnetic material as that for the enhancing layer may be used. For example, when the recording layer is formed of a ferromagnetic material containing Co, Ni, or Fe, the auxiliary magnetic layer may be formed of a ferromagnetic material containing a magnetic atom such as Co, Ni, or Fe at a higher concentration as compared with the recording layer. The auxiliary magnetic layer may be also formed of a metal simple substance such as Co, Ni, or Fe, or CoNiFe alloy. Alternatively, the

auxiliary magnetic layer may be formed of an alloy containing Co, Ni, or Fe and a transition metal, especially a noble metal such as Pt, Au, Ag, Cu, and Pd. As described above, by the auxiliary magnetic layer formed with the same ferromagnetic material as that for the above-mentioned enhancing layer, the exchange coupling force, generated between the auxiliary magnetic layer and the recording layer, is larger than the exchange coupling force generated between the magnetization-stabilizing layer and the recording layer of the magnetic recording medium as described in the section of prior art. Therefore, the thermal stability of the recording layer is further increased, thereby making it possible to realize further advanced high density recording.

[0028]

As described above, the magnetic recording medium of the first aspect of the present invention further stabilizes the magnetization of the recording layer, which is stabilized in the magnetization-stabilizing layer, by providing the enhancing layer in order to increase the exchange coupling force between the magnetization-stabilizing layer and the recording layer. On the other hand, in the magnetic recording medium of the third aspect of the present invention, a strong exchange coupling force is generated between the auxiliary magnetic layer and the

recording layer, it is therefore possible to stabilize the magnetization of the recording layer, in the same manner as in the case of the magnetic recording medium according to the first aspect as described above. Therefore, the magnetic recording medium of the third aspect of the present invention can increase the thermal stability of the recording layer with a simpler constitution as compared with the magnetic recording medium of the first aspect.

[0029]

In the magnetic recording medium according to the third aspect of the present invention, it is preferred that the auxiliary magnetic layer has a film thickness of 1 to 5 nm in order to effect a significant exchange coupling force exerted between the auxiliary magnetic layer and the recording layer.

[0030]

In the magnetic recording medium of the third aspect of the present invention, an enhancing layer may be provided between the non-magnetic layer and the recording layer in order to further increase an exchange coupling force generated between the recording layer and the auxiliary magnetic layer. The enhancing layer may be formed using the same material as that for the enhancing layer of the magnetic recording medium of the first aspect. It is preferred that the enhancing layer as described above

has a film thickness of 0.2 nm to 2.0 nm in order to obtain a significant enhancing effect of the exchange coupling force exerted between the recording layer and the auxiliary magnetic layer.

[0031]

The third magnetic recording medium of the present invention may further comprise a substrate, a second non-magnetic layer, and a magnetization-stabilizing layer which thermally stabilizes magnetization of the recording layer, wherein the second non-magnetic layer and the magnetization-stabilizing layer may exist between the auxiliary magnetic layer and the substrate, and the second non-magnetic layer may be positioned on a side which is near to the auxiliary magnetic layer. The second non-magnetic layer may be formed of the same material as that for the non-magnetic layer as described above, and the magnetization-stabilizing layer may be formed of the same material as that for, for example, the recording layer. The magnetic recording medium as described above can further stabilize the magnetization of the recording layer by the magnetization-stabilizing layer.

[0032]

Further, the magnetic recording medium of the third aspect of the present invention may comprise a substrate, a second non-magnetic layer, and a second auxiliary magnetic

layer, wherein the second non-magnetic layer and the second auxiliary magnetic layer may exist between the substrate and the auxiliary magnetic layer, and the second non-magnetic layer may be positioned on a side which is near to the auxiliary magnetic layer. The second auxiliary magnetic layer may be formed by using the same material as that for the enhancing layer as described above. The magnetic recording medium having the structure as described above is extremely excellent in thermal stability, because the exchange coupling magnetic field is further increased by forming the second auxiliary magnetic layer.

[0033]

According to a fourth aspect of the present invention, there is provided a magnetic recording apparatus comprising:

the magnetic recording medium according to the first, the second or the third aspect of the present invention;

a magnetic head which is used to record or reproduce information on the magnetic recording medium; and

a driving unit which drives the magnetic recording medium with respect to the magnetic head.

[0034]

The magnetic recording apparatus according to the present invention is excellent in recording stability over a long period of time, because the magnetic recording

apparatus is installed with the magnetic recording medium which is excellent in thermal stability.

[0035]

[EMBODIMENT OF THE INVENTION]

The magnetic recording medium and the magnetic recording apparatus according to the present invention will be specifically explained below in accordance with embodiments and Comparative Examples. However, the present invention is not limited to the embodiments.

[0036]

[FIRST EMBODIMENT]

Fig. 1 shows a sectional view of a typical embodiment of the magnetic recording medium according to the present invention. A magnetic recording medium 10 comprises, on a glass substrate 20, a first underlying base layer 2, a second underlying base layer 4, a magnetization-stabilizing layer 6, a first enhancing layer 8, a magnetic coupling layer (non-magnetic layer) 12, a second enhancing layer 8, a recording layer 16, and a protective layer 18. The respective layers were formed as follows by sputtering using a DC magnetron sputtering apparatus.

[0037]

An NiAl film was formed as the first metal underlying base layer 2 on the glass substrate 20 having a diameter of 2.5 inches (6.25 cm) by means of sputtering by using the DC

magnetron sputtering apparatus. An NiAl alloy having an atomic ratio of Ni:Al = 50:50 was used for a target. The NiAl film had a film thickness of 50 nm. The Ar gas pressure during the sputtering was 0.3 Pa, and the introduced electric power was 0.5 kW. The substrate was heated to 340 °C after the pressure of the sputtering chamber was reduced to be not more than 1 x 10^{-5} Pa before starting the sputtering. The speed of film formation was about 3 nm/second under this condition.

[0038]

A CrMo film was formed as the second metal underlying base layer 4 to have a film thickness of 20 nm on the first metal underlying base layer 2. A CrMo alloy containing Mo by 27 atomic % was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0039]

A CoCrPtB film was formed as the magnetization-stabilizing layer 6 to have a film thickness of 6 nm on the first metal underlying base layer 4. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0040]

Subsequently, a Co film was formed as the first

enhancing layer 8 to have a film thickness of 1 nm on the magnetization-stabilizing layer 6. Co was used for a target. The film formation during the sputtering was the same as that for the first metal underlying base layer 2 except that the introduced electric power was 100 W, and the spacing distance between the substrate and the target was lengthened.

[0041]

Subsequently, an Ru film was formed as the magnetic coupling layer 12 to have a film thickness of 0.8 nm on the first enhancing layer 8. Ru was used for a target. The film formation condition during the sputtering was the same as that for the first enhancing layer 8.

[0042]

A Co film was formed as the second enhancing layer 14 in the same manner as the first enhancing layer 8. The first enhancing layer 8 and the second enhancing layer 14 function to increase the exchange coupling between the recording layer 16 and the magnetization-stabilizing layer 6.

[0043]

A CoCrPtB film having magnetization in the in-plane direction was formed as the recording layer 16 to have a film thickness of 18 nm on the second enhancing layer 14. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film

formation condition was the same as that for the magnetization-stabilizing layer 6.

[0044]

Finally, a carbon layer was formed as a protective film to have a film thickness of 5 nm on the CoCrPtB recording layer 16. The film formation condition was the same as that for the first metal underlying base layer 2. Thus, the magnetic disk 10 having the structure shown in Fig. 1 was produced.

[0045]

[Comparative Example 1]

A magnetic disk was produced as Comparative Example in the same manner as in the first embodiment except that the first and second enhancing layers were not formed. Fig. 7 shows a structure of the magnetic disk 50 of Comparative Example obtained as described above.

[0046]

[Evaluation of Magnetization Curve]

The magnetic characteristics of the magnetic disk produced in the first embodiment were measured as follows. The magnetic field was applied with VSM (Vibration Sample Magnetometer) to observe the magnetization curve with respect to the external magnetic field. An obtained result is shown in Fig. 4. As appreciated from a hysteresis loop shown in Fig. 4, an area exists, in which the magnetization

is suddenly lowered before the external magnetic field is zero when the external magnetic field is lowered after the external magnetic field in the positive direction is applied to saturate the magnetization. In this area, a point appears, at which the rate of change of magnetization with respect to the external magnetic field ($\delta M/\delta H$) is locally maximized. In this area, the magnetization curve depicts a minor loop which exhibits hysteresis. The reason why the minor loop appears is considered as follows. That is, the direction of magnetization of the recording layer 16 is parallel to that of the magnetization-stabilizing layer 6 before arrival at the local maximum point of the rate of change. However, the direction of magnetization of the magnetization-stabilizing layer 6 is inverted at the local maximum point.

[0047]

Fig. 5(a) shows a magnified view of the minor loop. The minor loop resides in the magnetization curve which has been obtained such that the external magnetic field in the positive direction is applied to saturate the magnetizations of the recording layer and the magnetization-stabilizing layer, and then the magnetic field is lowered to stabilize the rate of change of magnetization, followed by increasing the external magnetic field again. It is noted that the magnetic field H, which

is obtained at the center of the loop and which is located at the midpoint between the upper end and the lower end of the minor loop, is known as the exchange coupling magnetic field H_{ex} which exhibits the exchange coupling of magnetization between the recording layer 16 and the stabilizing layer 6. It has been revealed that H_{ex} is 1.4 kOe in the case of the magnetic disk obtained in this embodiment. On the other hand, in the case of the magnetic disk of Comparative Example, a hysteresis minor loop as shown in Fig. 5(b) is obtained, for which it has been revealed that H_{ex} is 0.4 kOe. Therefore, the exchange coupling force between the recording layer and the magnetization-stabilizing layer is remarkably improved in the present invention, because the first and second enhancing layers are provided at the interface between the recording layer and the magnetic coupling layer and at the interface between the magnetic coupling layer and the magnetization-stabilizing layer, respectively. For reference, it has been reported that the magnetic disk, which is disclosed in the literature described in the section of prior art, has H_{ex} of about 450 (Oe).

[0048]

Further, the volume of activation V of each of the magnetic recording media obtained in the first embodiment and Comparative Example was measured to determine the value

Ku•V/(k•T) as an index of thermal stability of the magnetic recording medium. As a result, the value was about 71 in the case of the magnetic recording medium of the first embodiment, while the value was 65 in the case of the magnetic recording medium of Comparative Example. Also from this fact, it is understood that the magnetic recording medium of the present invention is excellent in thermal stability. Further, in the case of the magnetic recording medium of the embodiment, Brt (=4πMr•t (wherein Mr represents the residual magnetic field, and t represents the thickness)), which is an index to exhibit the possibility of high density recording of the in-plane magnetic recording medium, was about 44 Gμm.

[0049]

[First Modified Embodiment]

In the magnetic disk according to the present invention, the enhancing layer, which enhances the exchange coupling between the recording layer and the magnetization-stabilizing layer, may be provided at any one of the interface between the recording layer and the magnetic coupling layer (non-magnetic layer) and the interface between the magnetic coupling layer and the magnetization-stabilizing layer. As a modified embodiment of the first embodiment, Fig. 2 shows a structure of a magnetic disk 30 in which the first enhancing layer is not formed, and Fig.

3 shows a structure of a magnetic disk 40 in which the second enhancing layer is not formed.

[0050]

[Second Modified Embodiment]

In the first embodiment, each one layer of the magnetization-stabilizing layer 6 and the magnetic coupling layer 12 has been formed. However, two layers of the former and the two layer of the latter may be formed. That is, it is possible to provide a structure comprising, on a second underlying base layer 4 of CrMo, a first magnetization-stabilizing layer of CoCrPtB, a first enhancing layer, a first magnetic coupling layer of Ru, a second enhancing layer of Co, a second magnetization-stabilizing layer of CoCrPtB, a third enhancing layer, a second magnetic coupling layer of Ru, a fourth enhancing layer of Co, a recording layer of CoCrPtB, and a protective layer of carbon. In this case, the first and second enhancing layers (auxiliary enhancing layers) function to increase the exchange coupling between the first and second magnetization-stabilizing layers. The third and fourth enhancing layers function to increase the exchange coupling between the recording layer and the second magnetization-stabilizing layer. Alternatively, in the magnetic disk 30 shown in Fig. 2, a second magnetization-stabilizing layer, a second magnetic coupling layer, and a fourth enhancing

layer may be provided between the second enhancing layer 14 and the recording layer 16. Further, in the magnetic disk 40 shown in Fig. 3, a second magnetization-stabilizing layer, a fourth enhancing layer, and a second magnetic coupling layer may be provided between the magnetic coupling layer 12 and the recording layer 16.

[0051]

[Second Embodiment]

A plurality of magnetic disks were produced in accordance with the same process as that used in the first embodiment. A lubricant was applied onto the protective layers of the respective disks, and then the disks were coaxially attached to a spindle of a magnetic recording apparatus. A schematic arrangement of the magnetic recording apparatus is shown in Figs. 8 and 9. Fig. 8 shows a top view of the magnetic recording apparatus, and Fig. 9 shows a cross-sectional view of the magnetic recording apparatus 60 taken along a broken line A-A' shown in Fig. 8. A thin film magnetic head, which was based on the use of a soft magnetic film having a high saturation magnetic flux density of 2.1 T, was used as a recording magnetic head. A dual spin bulb-type magnetic head, which had the giant magnetic resistance effect, was used for the purpose of reproduction. The recording magnetic head and the reproducing magnetic head were integrated into one

unit, and they are indicated as a magnetic head 53 in Figs. 8 and 9. The integrated type magnetic head 53 is controlled by a magnetic head-driving system 54. The plurality of magnetic disks 10 are coaxially rotated by the spindle 52 of a rotary driving system 51. The distance between the magnetic disk and the magnetic head surface of the magnetic recording apparatus was maintained to be 11 nm. A signal corresponding to 40 Gbits/inch^2 (6.20 Gbits/cm^2) was recorded on the magnetic disk to evaluate S/N of the magnetic disk. As a result, a reproduction output of 25 dB was obtained.

[0052]

In order to evaluate the recording stability of the magnetic recording apparatus 60, the magnetic recording apparatus 60 was placed in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 24.3 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 3 %.

[0053]

[Comparative Example 2]

The magnetic disk 50 of Comparative Example was incorporated into the magnetic recording apparatus in the

same manner as in the second embodiment. In order to evaluate the recording stability of the magnetic recording apparatus, the magnetic recording apparatus 60 was placed in an environment at 80 °C at a humidity of 80 % for 100 hours. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 22.5 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 10 %. Therefore, it is appreciated that the magnetic recording apparatus provided with the magnetic disk of the present invention is excellent in recording stability.

[0054]

[Third Embodiment]

A schematic arrangement of another specified embodiment of the magnetic recording medium according to the present invention is shown in Fig. 10. The magnetic recording medium 70 comprises, on a glass substrate 20, a first underlying base layer 2, a second underlying base layer 4, an auxiliary magnetic layer 78, a magnetic coupling layer (non-magnetic layer) 12, a recording layer 16, and a protective layer 18. The respective layers were formed as follows by sputtering using a DC magnetron sputtering apparatus.

[0055]

At first, a glass substrate having a diameter of 2.5 inches (6.25 cm) was charged into a preparatory chamber of the DC magnetron sputtering apparatus. The pressure of the preparatory chamber was reduced so that the degree of vacuum was 1×10^{-5} Pa. After that, the glass substrate was heated at 200 °C for 10 minutes in order to remove any water from the surface of the glass substrate. Subsequently, the glass substrate was transported from the preparatory chamber to a film formation chamber having a degree of vacuum of 1×10^{-5} Pa. The glass substrate was heated to 340 °C in the film formation chamber.

[0056]

An NiAl film was formed as the first metal underlying base layer 2 on the heated glass substrate 20. An NiAl alloy having Ni:Al = 50:50 in atomic ratio was used for a target. The NiAl film had a film thickness of 50 nm. The Ar gas pressure during the sputtering was 0.3 Pa, and the introduced electric power was 500 W.

[0057]

A CrMo film was formed as the second metal underlying base layer 4 to have a film thickness of 20 nm on the first metal underlying base layer 2. A CrMo alloy containing Mo by 27 atomic % was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0058]

Subsequently, a CoPt film was formed as the auxiliary magnetic layer 78 to have a film thickness of 2 nm on the second metal underlying base layer. A CoPt alloy containing Pt by 17 atomic % was used for a target. The film formation condition during the sputtering was the same as that for the first metal underlying base layer 2 except that the introduced electric power was 100 W, and the spacing distance between the substrate and the target was lengthened.

[0059]

Subsequently, an Ru film was formed as the magnetic coupling layer 12 to have a film thickness of 0.8 nm on the auxiliary magnetic layer 78. Ru was used for a target. The film formation condition during the sputtering was the same as that for the auxiliary magnetic layer 78.

[0060]

A CoCrPtB film having magnetization in the in-plane direction was formed as the recording layer 16 to have a film thickness of 18 nm on the magnetic coupling layer. A $Co_{64}Cr_{20}Pt_{12}B_4$ alloy was used for a target. The film formation condition was the same as that for the first metal underlying base layer 2.

[0061]

Finally, a carbon layer was formed as the protective

film to have a film thickness of 5 nm on the recording layer 16 of CoCrPtB. The film formation condition was the same as that for the first metal underlying base layer 2. Thus, the magnetic disk 70 having the structure shown in Fig. 10 was produced.

[0062]

The magnetic field was applied to the magnetic disk obtained as described above with VSM in the same manner as in the first embodiment to observe the magnetization curve with respect to the external magnetic field. An obtained result is shown in Fig. 11. As understood from the hysteresis loop, in the same manner as in the magnetic disk produced in the first embodiment, an area also existed in the magnetic disk produced in this embodiment, in which the magnetization is suddenly lowered before the external magnetic field is zero when the external magnetic field is lowered after the external magnetic field in the positive direction is applied to saturate the magnetization. As appreciated from Fig. 11, the magnetization curve depicts a minor loop which exhibits hysteresis in this area. A magnified view of the minor loop is shown in the lower part of Fig. 11. The exchange coupling magnetic field H_{ex} was determined from the minor loop, in the same manner as in the magnetic disk produced in the first embodiment. As a result, the exchange coupling magnetic field H_{ex} was 1.7

kOe.

[0063]

Subsequently, a plurality of magnetic disks were produced in accordance with the same process as that described above. A lubricant was applied onto the protective layers of the respective magnetic disks. After that, the magnetic disks were incorporated into the magnetic recording apparatus shown in Figs. 8 and 9, in the same manner as in the second embodiment. A signal was recorded on the magnetic disk in the same manner as in the second embodiment by using the magnetic recording apparatus to evaluate S/N of the magnetic disk. As a result, a reproduction output of 25 dB was obtained.

[0064]

Subsequently, in order to evaluate the recording stability of the magnetic recording apparatus as described above, the magnetic recording apparatus was placed in an environment at 80 °C at a humidity of 80 % for 100 hours, in the same manner as in the second embodiment. After the passage of 100 hours, the recorded signal was reproduced to measure S/N of the magnetic disk. As a result, a reproduction output of 24.5 dB was obtained. That is, the rate of decrease of the recording signal in the environment described above was 2 %. Therefore, according to the comparison with the magnetic recording apparatus of

Comparative Example 2, it is understood that the magnetic recording apparatus provided with the magnetic disk of the present invention is excellent in recording stability.

[0065]

[Third Modified Embodiment]

As a modified embodiment of the magnetic disk produced in the third embodiment, an enhancing layer 79 may be provided at the interface between the magnetic coupling layer 12 and the recording layer 16 as shown in Fig. 12. The enhancing layer 79 may be formed by using the same material as that for the enhancing layer 8 of the magnetic disk produced in the first embodiment. The enhancing layer 79 functions to increase the exchange coupling between the recording layer 16 and the auxiliary magnetic layer 78.

[0066]

[Fourth Modified Embodiment]

As another modified embodiment of the magnetic disk produced in the third embodiment, a magnetization-stabilizing layer 86 and a second magnetic coupling layer 82 may be provided on the second underlying base layer 3 in order to further stabilize the magnetization of the recording layer 16 as shown in Fig. 13. The magnetization-stabilizing layer 86 may be formed by using the same material as that for the magnetization-stabilizing layer 6 of the magnetic disk produced in the first embodiment. Ru

may be used for the second magnetic coupling layer 82 in the same manner as in the third embodiment. As still another modified embodiment, the magnetic disk shown in Fig. 13 may be constructed by substituting the magnetization-stabilizing layer 86 with the enhancing layer used in the first embodiment.

[0067]

In the foregoing, the present invention has been specifically explained with reference to the embodiments. However, the present invention is not limited thereto. The substrate, the first metal underlying base layer, the second metal underlying base layer, the auxiliary magnetic layer, the magnetization-stabilizing layer, the magnetic coupling layer, the first enhancing layer, the second enhancing layer, and the recording layer may be constructed with a variety of known materials without being limited to the materials described in the embodiments.

[0068]

[EFFECTS OF THE INVENTION]

In the magnetic recording medium of the first aspect of the present invention, the exchange coupling force between the recording layer and the magnetization-stabilizing layer is increased owing to the existence of the enhancing layer. Therefore, the magnetic recording medium according to the first aspect is excellent in

thermal stability. Even when the minute magnetic domains are formed for the high density recording, then the thermal fluctuation scarcely occurs, and it is possible to stably retain the recorded information over a long period of time. Further, the magnetic recording medium of the second aspect of the present invention is excellent in thermal stability because the magnetic recording medium has an exchange coupling magnetic field of not less than 1kOe, thereby making it possible to realize the high-density recording. Furthermore, in the magnetic recording medium of the third aspect of the present invention, the strong exchange coupling force is generated between the recording layer and the auxiliary magnetic layer owing to the auxiliary magnetic layer which is formed of the ferromagnetic material having the high magnetic atom concentration as compared with the ferromagnetic material for forming the recording layer. Therefore, in the same manner as the magnetic recording medium of the first aspect, the magnetic recording medium according to the third aspect is excellent in thermal stability with a simpler layer constitution compared with that of the magnetic recording medium according to the first aspect.

[0069]

The magnetic recording apparatus, which is provided with the magnetic recording medium of the present

invention, is excellent in recording stability. It is possible to realize the super high density recording exceeding, for example, 40 Gbits/inch^2 (6.20 Gbits/cm^2).

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] Fig. 1 shows a cross-sectional structure of a magnetic disk according a first embodiment.

[Fig. 2] Fig. 2 shows a cross-sectional structure of a magnetic disk according to a modified embodiment of the first embodiment.

[Fig. 3] Fig. 3 shows a cross-sectional structure of a magnetic disk according to another modified embodiment of the first embodiment.

[Fig. 4] Fig. 4 shows a graph illustrating a hysteresis loop (major loop) of the magnetic disk according to the first embodiment.

[Fig. 5] Fig. 5 a graph illustrating a minor loop of the hysteresis loop shown in Fig. 4.

[Fig. 6] Fig. 6 shows a sectional view illustrating a structure of a conventional magnetic disk.

[Fig. 7] Fig. 7 shows a cross-sectional structure of a magnetic disk according to a comparative embodiment 1.

[Fig. 8] Fig. 8 shows a schematic arrangement of a magnetic recording apparatus according to an example of a second embodiment of the present invention as viewed from a position thereover.

[Fig. 9] Fig. 9 shows a sectional view as viewed in a direction of A-A' illustrating the magnetic recording apparatus shown in Fig. 8.

[Fig. 10] Fig. 10 shows a schematic cross-sectional structure of a magnetic disk manufactured in a third embodiment of the present invention.

[Fig. 11] Fig. 11 shows a graph illustrating a hysteresis loop (major loop) of the magnetic disk showin in Fig. 10, and a graph of enlarged image of a minor loop of the hysteresis loop.

[Fig. 12] Fig. 12 shows a schematic cross-sectional structure of a magnetic disk according to a modified embodiment of the third embodiment of the present invention.

[Fig. 13] Fig. 13 shows a schematic cross-sectional structure of a magnetic disk according to another modified embodiment of the third embodiment of the present invention.

[EXPLANATION OF REFERENCE NUMERALS]

2 first metal underlying base layer

4 second metal underlying base layer

6 magnetization-stabilizing layer

8 first enhancing layer

10 magnetic disk

12 magnetic coupling layer

14 first enhancing layer

16 recording layer

20 substrate

52 spindle

53 magnetic head

60 magnetic recording apparatus

78 auxiliary magnetic layer

[TITLE OF THE DOCUMENT] Abstract

[ABSTRACT]

[PROBLEMS] To provide a magnetic recording medium for high-density recording which is excellent in thermal stability.

[MEANS TO SOLVE PROBLEMS] An in-plane magnetic recording medium 10 comprises, on a substrate 20, a first underlying base layer 2 of NiAl, a second underlying base layer 4 of CrMo, a magnetization-stabilizing layer 6 of CoPt, a magnetic coupling layer 12 of Ru, a second enhancing layer 8 of Co, a recording layer 16 of CoCrPtB, and a protective layer 18 of carbon. The magnetization-stabilizing layer 6 stabilizes the magnetization of the recording layer 16, and the magnetic coupling layer 12 provides the exchange coupling force which exerts between the recording layer 16 and the magnetization-stabilizing layer 6. The exchange coupling is remarkably improved by providing a first enhancing layer 8 of Co and a second enhancing layer 14 of Co in the interface between the magnetic coupling layer 12 and the magnetization-stabilizing layer 6 and in the interface between the magnetic coupling layer 12 and the recording layer 16, respectively. Accordingly, it is possible to provide a magnetic recording apparatus which is excellent in recording stability over a long period of time in which the

thermal stability of the magnetic recording medium is excellent.

[SELECTED DRAWINGS] Fig. 1

[TITLE OF THE DOCUMENT] Drawing

Fig. 1

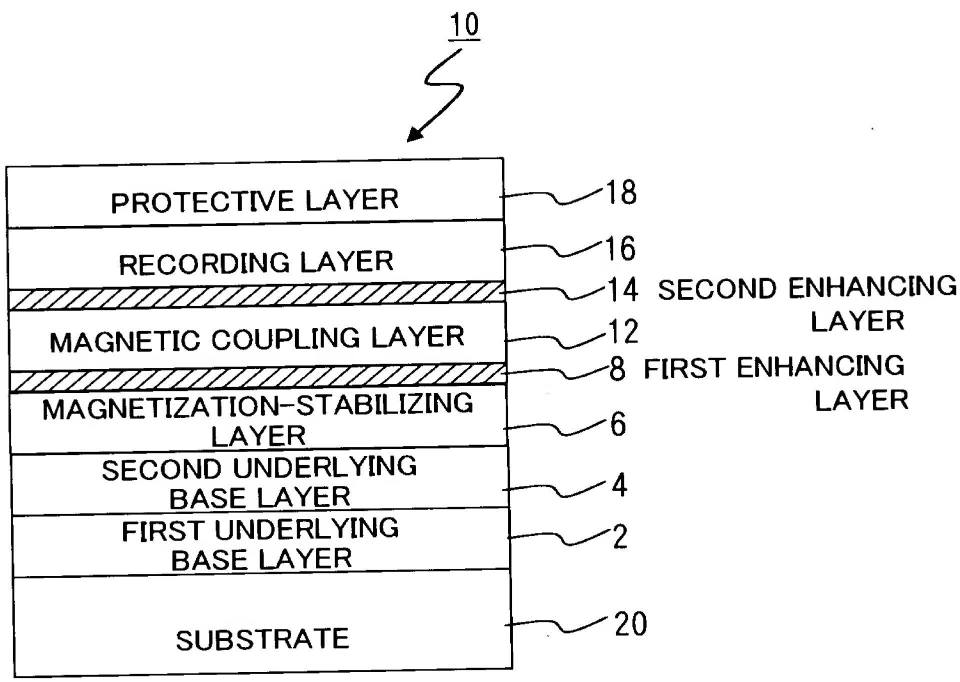
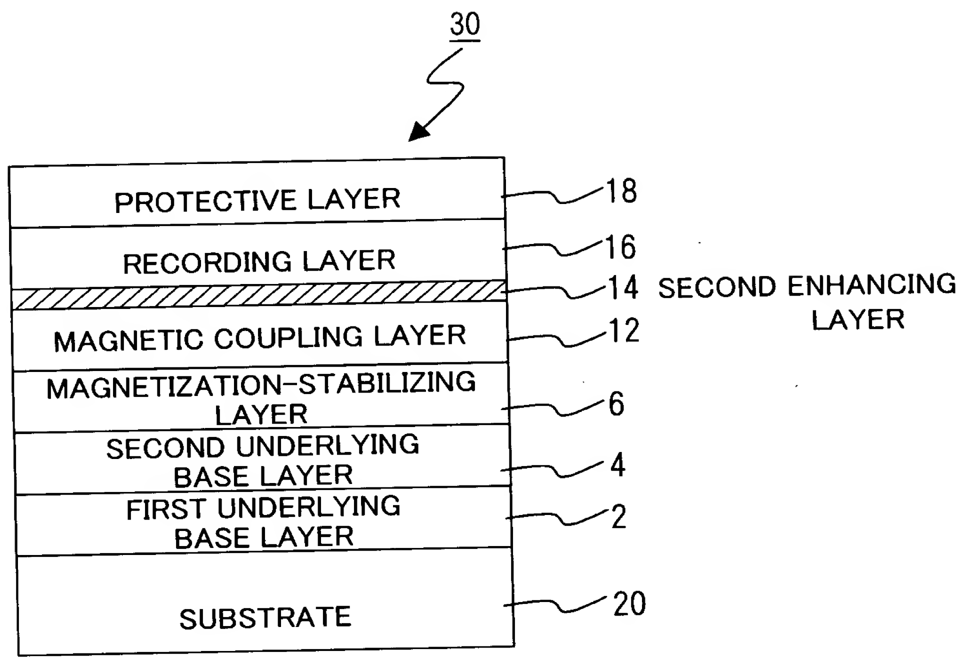


Fig. 2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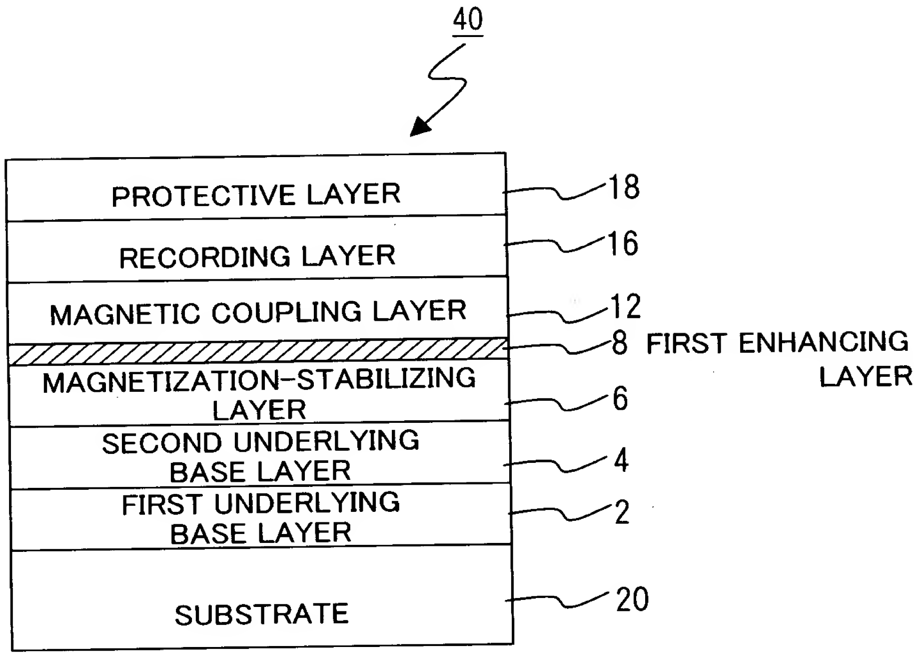
PROTECTIVE LAYER
18
RECORDING LAYER
16
14
SECOND ENHANCING LAYER
MAGNETIC COUPLING LAYER
12
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 3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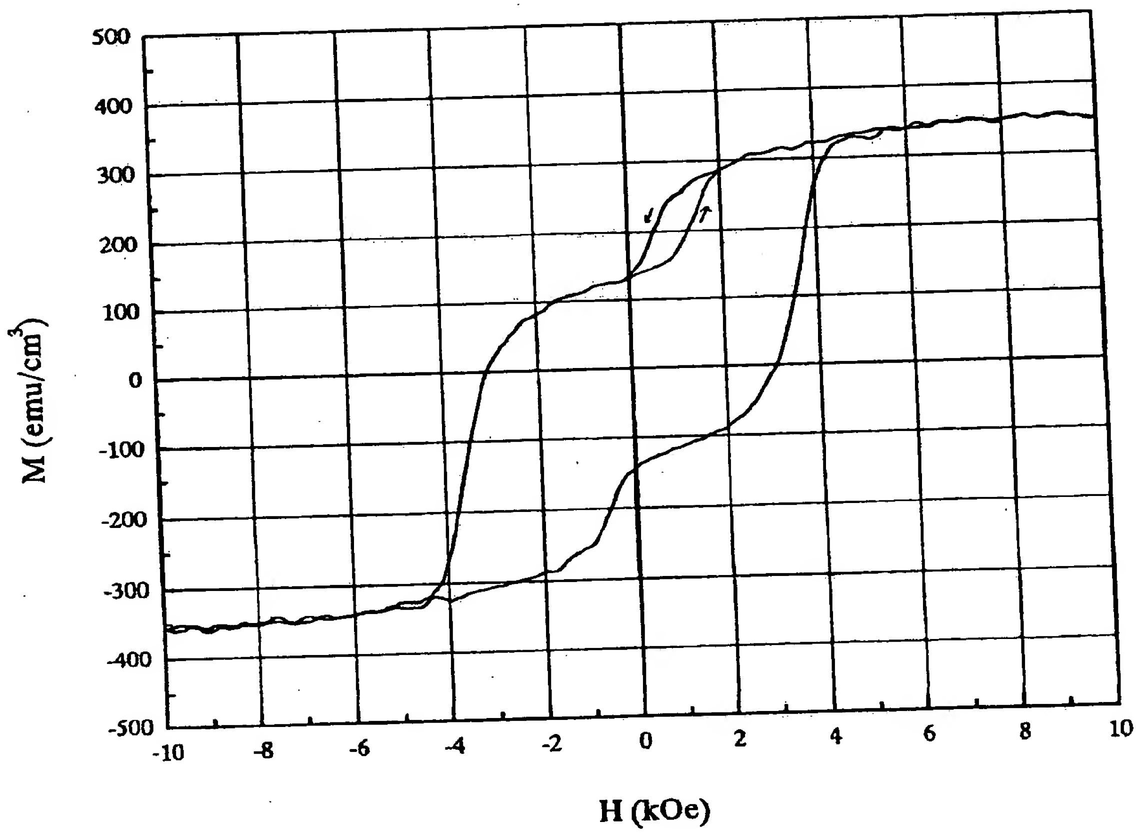
PROTECTIVE LAYER
18
RECORDING LAYER
16
MAGNETIC COUPLING LAYER
12
8 FIRST ENHANCING LAYER
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 4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400
300
200
100
0
-100
-200
-300
-400
-500
M (emu/cm³)
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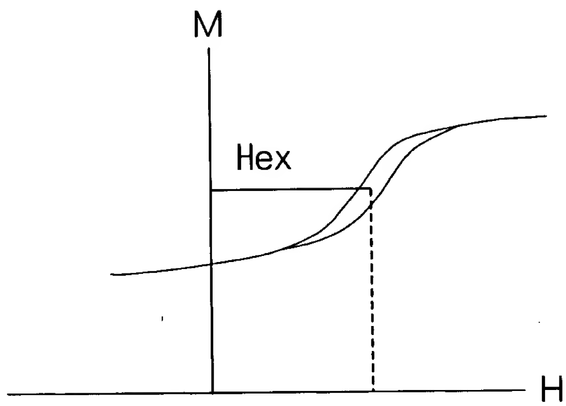
-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)

Fig. 5

(a)



(b)

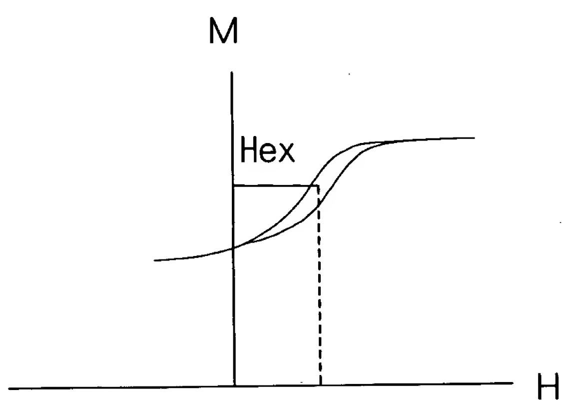


Fig. 6

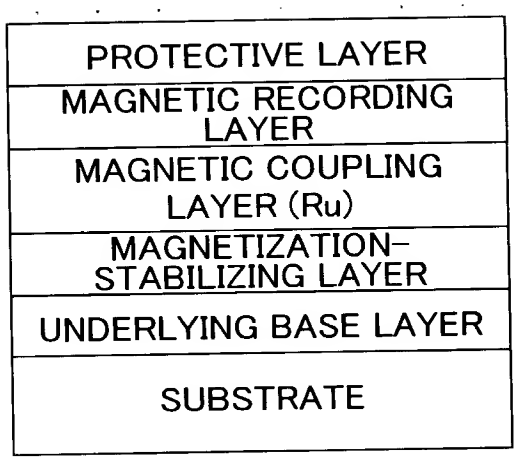
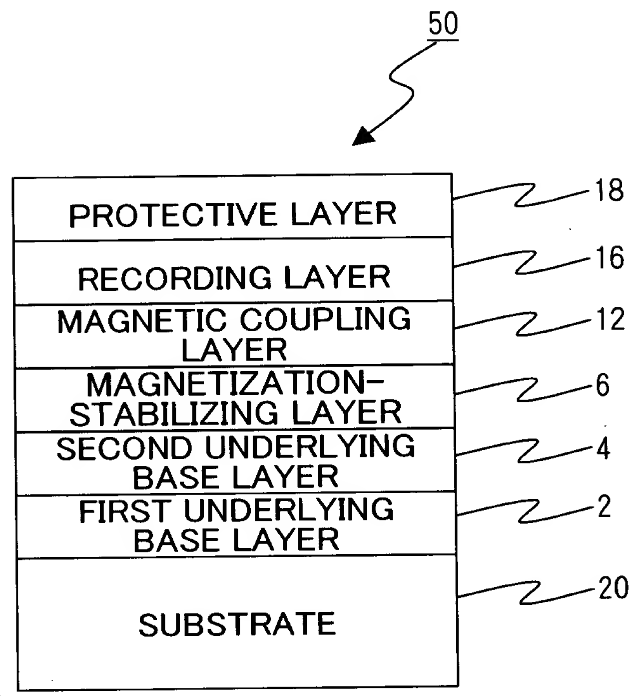

PROTECTIVE LAYER
MAGNETIC RECORDING LAYER
MAGNETIC COUPLING LAYER (Ru)
MAGNETIZATION-STABILIZING LAYER
UNDERLYING BASE LAYER
SUBSTRATE

Fig. 7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PROTECTIVE LAYER
18
RECORDING LAYER
16
MAGNETIC COUPLING LAYER
12
MAGNETIZATION-STABILIZING LAYER
6
SECOND UNDERLYING BASE LAYER
4
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 8

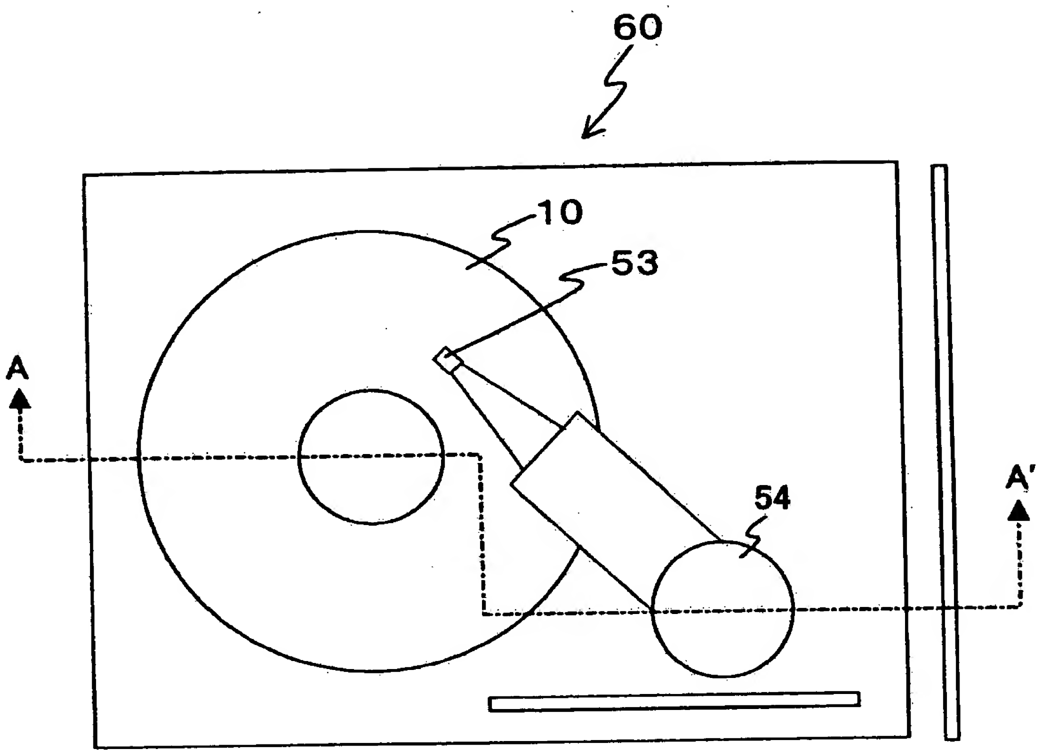


Fig. 9

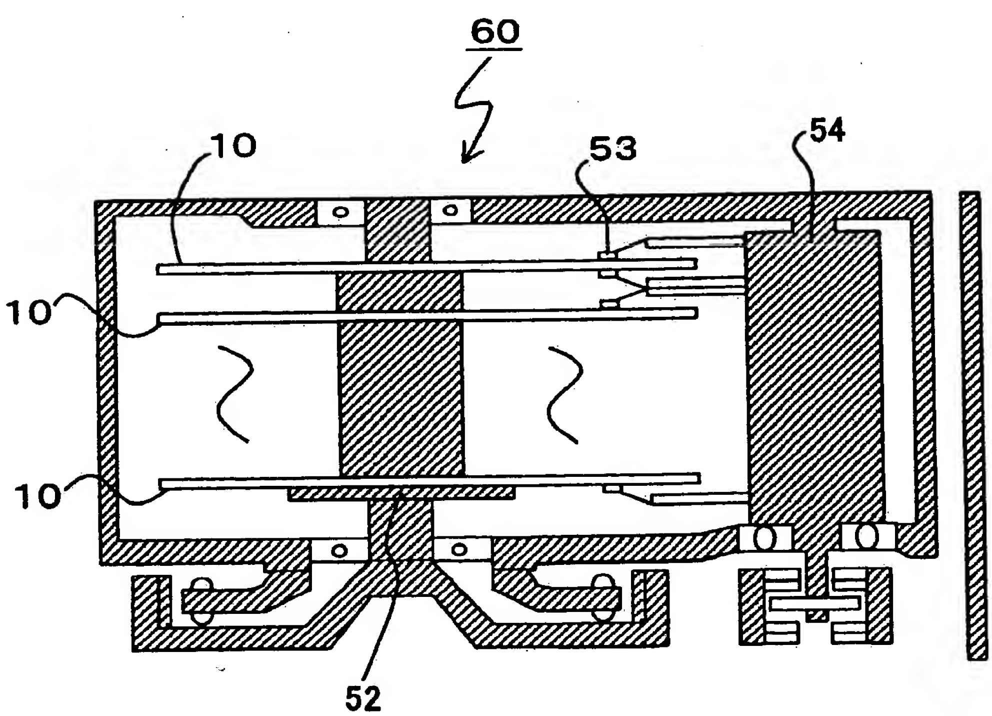
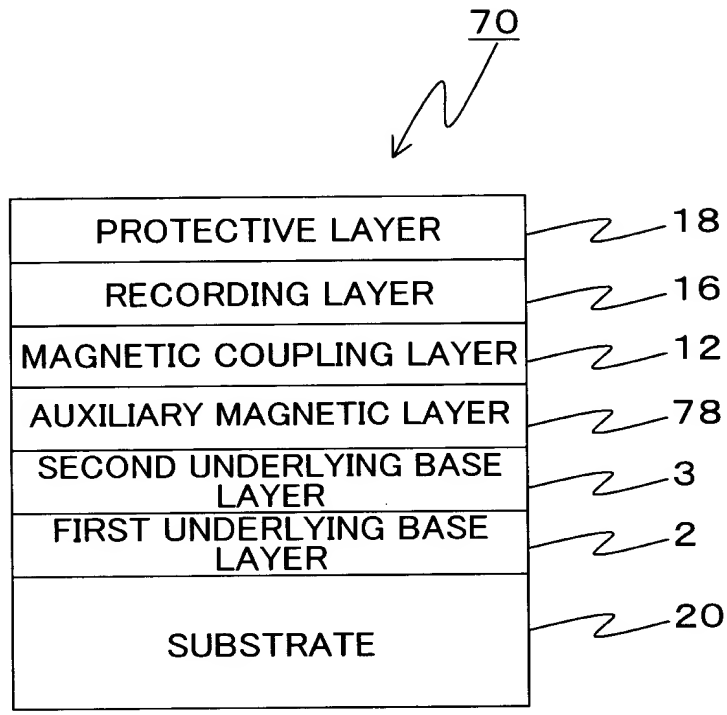


Fig. 10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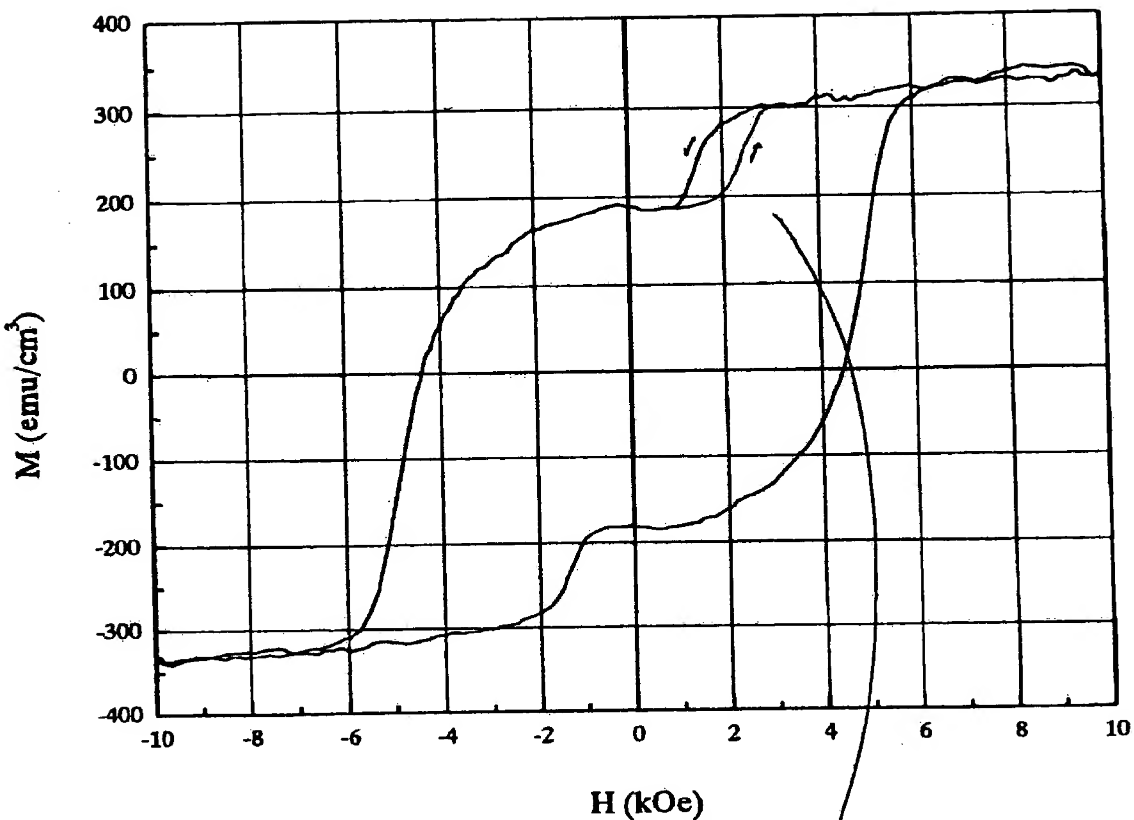
PROTECTIVE LAYER
18
RECORDING LAYER
16
MAGNETIC COUPLING LAYER
12
AUXILIARY MAGNETIC LAYER
78
SECOND UNDERLYING BASE LAYER
3
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 11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100
0
-100
-200
-300
-400
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-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)

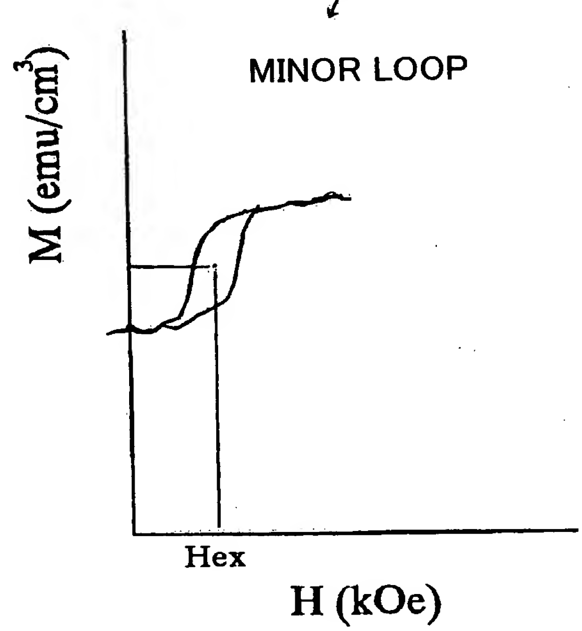
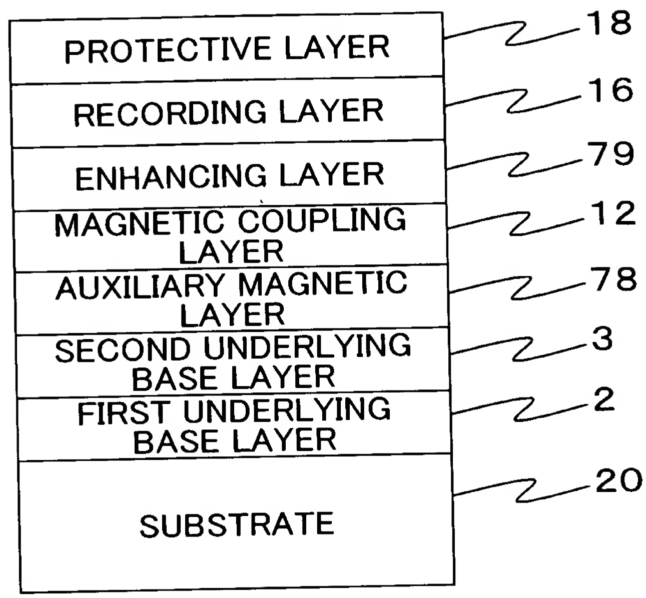

MINOR LOOP
M (emu/cm3)
Hex
H (kOe)

Fig. 12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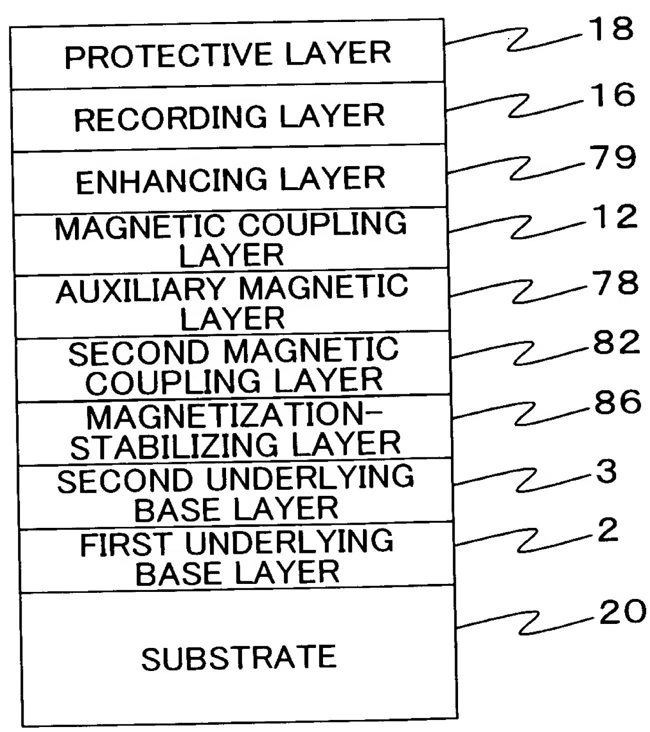
RECORDING LAYER
16
ENHANCING LAYER
79
MAGNETIC COUPLING LAYER
12
AUXILIARY MAGNETIC LAYER
78
SECOND UNDERLYING BASE LAYER
3
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20

Fig. 13


PROTECTIVE LAYER
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RECORDING LAYER
16
ENHANCING LAYER
79
MAGNETIC COUPLING LAYER
12
AUXILIARY MAGNETIC LAYER
78
SECOND MAGNETIC COUPLING LAYER
82
MAGNETIZATION-STABILIZING LAYER
86
SECOND UNDERLYING BASE LAYER
3
FIRST UNDERLYING BASE LAYER
2
SUBSTRATE
20